From:	Clay Patmont
To:	Miller, Garyg
Cc:	Baumgarten, Gary
Subject:	Anthropogenic Background
Date:	Wednesday, May 9, 2018 12:06:15 PM
Attachments:	cover.pdf ch2.pdf Important Considerations in the Derivation of Background at Sediment Sit....pdf

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Gary –

Following up on our discussion yesterday, attached are some documents that discuss anthropogenic background and how it relates to CERCLA sediment cleanup actions. Gary B. is likely all over this stuff. Hope this is helpful. Let me know if you have any questions. Thanks -

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2.0 REMEDIAL INVESTIGATION CONSIDERATIONS

The main purpose of investigating contaminated sediment, as with other media, is generally to determine the nature and extent of contamination to determine if there are unacceptable risks that warrant a response and, if so, to evaluate potential remedies. Investigations may be conducted by a number of different parties under a number of different legal authorities. Most of this chapter presents general information of potential use to any investigator. However, the language and program-specific references are drawn from the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program, and at times, from the Resource Conservation and Recovery Act (RCRA) program. This chapter is not a comprehensive guide to site characterization and risk assessment of sediment sites, but it does attempt to summarize many of the most important considerations.

Under CERCLA, the investigation process is known as a "remedial investigation" (RI). Under RCRA, the investigation process is known as a "RCRA facility investigation." The RI process is described in the U.S. Environmental Protection Agency's (EPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (U.S. EPA 1988a, also referred to as the "RI/FS Guidance"). The investigative process in a RCRA corrective action is best described in Office of Solid Waste and Emergency Response (OSWER) Directive 9902.3-2A, *RCRA Corrective Action Plan* (U.S. EPA 1994a), and the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR) 61 *Federal Register* (*FR*) 19447]. This chapter supplements these existing guidances by offering brief sediment-specific guidance about site characterization, risk assessment, and other investigation issues unique to sediment. More detailed guidance concerning site characterization is beyond the scope of this document, but may be developed as needed in the future.

2.1 SITE CHARACTERIZATION

The site characterization process for a contaminated sediment site should allow the project manager to accomplish the following general goals, at a scale and complexity appropriate to the site:

- Identify and quantify the contaminants present in sediment, surface water, biota, flood plain soils, and in some cases, ground water;
- Understand the vertical and horizontal distribution of the contaminants within the sediment and flood plains;
- Identify the sources of historical contamination and quantify any continuing sources;
- Understand the geomorphological setting and processes (e.g., resuspension, transport, deposition, weathering) affecting the stability of sediment;
- Understand the key chemical, and biological processes affecting the fate, transport, and bioavailability of contaminants;
- Identify the complete or potentially complete human and ecological exposure pathways for the contaminants;

- Identify current and potential future human and ecological risks posed by the contaminants;

- Collect data necessary to evaluate the potential effectiveness of natural recovery, in-situ capping, sediment removal, and promising innovative technologies; and

- Provide a baseline of data that can be used to monitor remedy effectiveness in all appropriate media (generally sediment, water, and biota).

The project manager, in consultation with technical experts and stakeholders, should develop site-specific investigation goals that are of an appropriate scope and complexity for the site. Systematic planning, dynamic work strategies, and, where appropriate, real-time measurement technologies may be useful at sediment sites. Combined, these three strategies are known as the "triad approach," described on EPA's Innovative Technologies Web site at http://www.cluin.org/triad (although the term "triad" is the same, this approach should not be confused with the approach to ecological risk assessment known by the same name). This approach attempts to summarize the best current practices in site characterization to collect the "correct" data, improve confidence in results, and save cost. The triad approach resources also include EPA (2003b), Crumbling (2001), and Lesnick and Crumbling (2001).

Data collection during the remedial investigation frequently has multiple uses, including human health and ecological risk assessment, identification of potential early actions, and remedy decision-making. It is important to consult as many data users as possible (e.g., risk assessors, modelers, as well as quality assurance/quality control (QA/QC) experts) early in the scoping process and throughout data collection.

Data should be of a type, quantity, and quality to meet the objectives of the project. The EPA's data quality objective (DQO) process is one method to achieve this, as described below. Where other agencies (e.g., natural resource trustee agencies, state remediation agencies, and health departments) have an interest at the site, they should be consulted concerning decisions about DQOs so that collected data can serve multiple purposes, if possible. In addition, the community and other stakeholders [e.g., local governments and potentially responsible parties (PRPs)] should be consulted in these decision as appropriate.

2.1.1 Data Quality Objectives

The EPA's DQO process is intended to help project managers collect data of the right type, quality, and quantity to support site decisions. As described in *Guidance for the Data Quality Objective Process* (U.S. EPA 2000a), seven steps generally guide the process. The initial steps help assure that only data important to the decisions that need to be made are collected. The seven DQO process steps include the following, with an example provided in the context of a risk assessment:

1. *State the problem*. Example: There is current exposure of humans to site-related contaminants through eating fish.

2. *Identify the decision*. Example: Is the exposure causing an unacceptable risk?

3. *Identify inputs to the decision*. Examples: What are the appropriate fish species, receptor groups, and consumption rates to evaluate? What existing data are available and what must be collected? What is the toxicity of the contaminants to all receptor groups?

4. *Define boundaries of study.* Example: For purposes of the human health risk assessment, should the water body and the human population each be considered as a whole or in subparts?

5. *Develop a decision rule.* Example: If exposure at the upper 95 percent confidence limit for fish consumption of the recreational fisher population to the mean contaminant concentration of any one of the three most popular fish species exceeds a cancer risk range of 10^{-6} to 10^{-4} or a Hazard Index of 1, risk will be considered unacceptable.

6. *Specify limits on decision errors*. Example: What levels of uncertainty are acceptable for this decision, considering both false positive and false negative errors?

7. *Optimize the design for obtaining data.* Example: What is the most resource-effective fish sampling and analysis design for generating data that will meet the data quality objectives?

Similar hypotheses could be established for evaluating each remedial alternative being considered for the site, and for evaluating the effectiveness of the selected alternative. The way in which the process is followed may vary depending on the decision to be made, from a thought process to a rigorous statistical analysis. Additional guidance provided in *EPA Requirements for Quality Assurance Project Plans* [(QAPPs), U.S. EPA 2001e) describes how DQOs are incorporated into QAPPs.

2.1.2 Types of Data

The types of data the project manager should collect are determined mostly by the following information needed to:

- Develop the conceptual site model;
- Evaluate sediment and contaminant fate and transport;
- Conduct the human health and ecological risk assessments;
- Evaluate the effectiveness of source control;
- Evaluate potential remedies;
- Document baseline conditions prior to implementation of the remedy; and
- Design and implement the selected remedy.

Highlight 2-1 lists some general types of physical, chemical, and biological data that a project manager should consider collecting when characterizing a sediment site. The project manager should understand the importance of historical changes in some of these characteristics (e.g., water body bathymetry or contaminant distributions in surface and subsurface sediment, water, and biota). It may also be important to understand how characteristics change seasonally, and under various flow and temperature conditions. The relative importance of these types of data variabilities is dependent on the site. It is frequently important to understand the properties affecting the mixing zone or biologically active zone of sediment. Contaminants in the biologically active layer of the surface sediment at a site often drive exposure, and reduction of surface sediment concentrations may be necessary to achieve risk reduction. While sediment sites typically demand more types of data for effective characterization than other types of sites, the type and quantity of data required should be geared to the complexity of the site and the weight of the decision. In addition, the data acquisition process should not prevent early action to reduce risk when appropriate.

Site characterization should include collection of sufficient baseline data to be used to compare to monitoring data collected during and following implementation of the remedy in a statistically defensible manner. Additional sampling could be needed during remedial design, however, to establish reliable baseline data for the monitoring program. Chapter 8, Remedial Action and Long-Term Monitoring, provides a discussion of effective monitoring programs, much of which is also useful during the remedial investigation.

At this time, polychlorinated biphenyls (PCBs) are among the most common contaminants of concern at contaminated sediment sites. The term “PCB” refers to a group of 209 different chemicals, called PCB congeners, sharing a similar structure. Aroclors are commercial mixtures of PCB congeners and weathering of an Aroclor after release into the environment results in a change in its congener composition (National Research Council, (NRC 2001). EPA’s Office of Water *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third Edition* (U.S. EPA 2000b), notes that individual PCB congeners may be preferentially enhanced in environmental media and in biota.

Characterizing PCB risk on a congener-specific basis allows for an accounting of the differences in physiochemical, biochemical, and toxicological behavior of the different congeners in type and magnitude of effects and, therefore, in risk calculations. Although Aroclor analysis can be useful for initial assessment of PCB concentrations, for risk assessment purposes, NRC recommends that PCB sites be characterized on the basis of specific PCB congeners and the total mixture of congeners found at each site (NRC 2001). EPA currently provides congener-specific analyses through its Non-Routine Program under the Contract Laboratory Program (CLP), but it may, in the future, be available through its CLP routine analytical services. However, to the extent that PCB congener-specific data are determined useful at a site, the project manager should not assume this necessarily needs to be done for all samples collected. At times, only a subset of samples or sampling events may need congener analysis. Deciding how best to characterize a PCB site is a complex issue due in part to issues related to dioxin-like PCBs, the lack of congener-specific toxicological data, the need for comparing present and previously collected data, and the cost of congener-specific analyses. The decision about what method or methods to use for PCB analysis should be made on a site-specific basis.

Highlight 2-1: Example Site Characterization Data for Sediment Sites

Physical

- Sediment particle size/distribution and mineralogy in cores
- In-situ porosity/bulk density
- Bearing strength
- Specific gravity
- Salinity profile of sediment cores
- Geometry/bathymetry of water body
- Turbidity
- Temperature
- Sediment resuspension and deposition rates
- Depth of mixing layer/ degree and depth of bioturbation
- Geophysical survey results
- Flood frequencies, annual and event-driven hydrographs and current velocities
- Tidal regime
- Ground water flow regime and surface water/ground water interaction
- Ice cover and break-up patterns
- Water uses causing physical disturbance of sediment

Chemical

- Near-surface contaminant concentrations in sediment
- Contaminant profiles in sediment cores
- Contaminant concentrations (especially metals) in biota tissue, ground water, and pore water
- Total organic carbon (TOC) in sediment
- Dissolved, suspended, and colloidal contaminant concentrations in surface water
- Simultaneously extracted metals (SEM) and acid volatile sulfide (AVS) in sediment
- Radiometric dating profiles in sediment cores
- Non-contaminant chemical species that may affect contaminant mobility
- Oxidation-reduction profile of sediment cores
- pH profile in sediment cores
- Carbon/nitrogen/ phosphorus ratio
- Non-ionized ammonia concentration in sediment

Biological

- Sediment toxicity
- Extent of recreational/commercial harvesting of fish/shellfish for human consumption
- Extent of predators dependent on aquatic food chain (e.g., mink, otter, kingfisher, heron)
- Abundance/diversity of bottom-dwelling species and fishes
- Abundance/diversity of emergent and submerged vegetation
- Habitat stressor analyses
- Contaminant bioavailability
- Pathological condition, such as presence of tumors in fish
- Presence of indicator species

Currently, metals are also among the most common contaminants of concern at Superfund sediment sites. Concentrations of bulk (total dry weight basis) metals in sediment alone are typically not good measures of metal toxicity. However, in addition to direct measurement of toxicity, EPA has developed a recommended approach for estimating metal toxicity based on the bioavailable metal fraction, which can be measured in pore water and/or predicted based on the relative sediment concentrations of acid volatile sulfide (AVS), simultaneously extracted metals (SEM), and total organic carbon (TOC) (U.S. EPA 2005c). Both AVS and TOC are capable of sequestering and immobilizing a range of metals in sediment.

2.1.3 Background Data

Where site contaminants may also have natural or anthropogenic (man-made) non-site-related sources, it may be important to establish background or reference data for a site. When doing so, project managers should consult EPA's *Role of Background in the CERCLA Cleanup Program* (U.S. EPA 2002b), the *EPA ECO Update - The Role of Screening-Level Risk Assessments and Refining Contaminants of Concern in Baseline Ecological Risk Assessments* (U.S. EPA 2001f), and *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (U.S. EPA 2002c). Although the latter is written specifically for soil, many of the concepts may be applicable to contaminant data for sediment and biota. It should be noted that a comprehensive investigation of all background substances found in the environment usually will not be necessary at CERCLA sites. For example, radon background samples would not be normally collected at a chemically contaminated site unless radon, or its precursor was part of the CERCLA release.

Where applicable, project managers should consider continuing atmospheric and other background contributions to sites to adequately understand contaminant sources and establish realistic risk reduction goals (U.S. EPA 2002b). For baseline risk assessments, EPA recommends an approach that generally includes the evaluation of the contaminants that exceed protective risk-based screening concentrations, including contaminants that may have natural or anthropogenic sources on and around the Superfund site under evaluation. When site-specific information demonstrates that a substance with elevated concentrations above screening levels originated solely from natural causes (i.e., is a naturally occurring substance and not release-related), these contaminant normally does not need to be carried through the quantitative analysis. However, these contaminants should be generally discussed in the risk characterization summary so that the public is aware of its existence. The presence of naturally occurring substances above screening levels may indicate a potential environmental or health risk, and that information should be discussed at least qualitatively in the document. If data are available, the contribution of background to site conditions should be distinguished (U.S. EPA 2002b). This approach is designed to ensure a thorough characterization of risks associated with hazardous substances, pollutants, and contaminants at sites (U.S. EPA 2002b).

For risk management purposes, understanding whether background concentrations are high relative to the concentrations of released hazardous substances, pollutants, and contaminants may help risk managers make decisions concerning appropriate remedial actions (U.S. EPA 2002b). Generally, under CERCLA, cleanup levels are not set at concentrations below natural or anthropogenic background levels (U.S. EPA 1996a, 1997c, 2000c). If a risk-based remediation goal is below background concentrations, the cleanup level for that chemical may be established based on background concentrations.

In cases where area-wide contamination may pose risks, but these risks are not appropriate to address under CERCLA, EPA may be able to help identify other programs or regulatory authorities that are able to address the sources of area-wide contamination, particularly anthropogenic sources (U.S. EPA 1996a, 1997c, 2000c). In some cases, as part of a response to address CERCLA releases of hazardous substances, pollutants, and contaminants, EPA may also address some of the background contamination that is present on a site due to area-wide contamination.

2.2 CONCEPTUAL SITE MODELS

A conceptual site model (CSM) generally is a representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources to receptors. For sediment sites, perhaps even more so than for other types of sites, the CSM can be an important element for evaluating risk and risk reduction approaches. The initial CSM typically is a set of hypotheses derived from existing site data and knowledge gained from other sites. Natural resource trustee agencies and other stakeholders may have information about the ecosystem that is important in developing the conceptual site model and it is recommended that they have input at this stage of the site investigation. This initial model can provide the project team with a simple understanding of the site based on available data. Information gaps may be discovered in development of the CSM that support collection of new data.

Essential elements of a CSM generally include information about contaminant sources, transport pathways, exposure pathways, and receptors. Summarizing this information in one place usually helps in testing assumptions and identifying data gaps and areas of critical uncertainty for additional investigation. The site investigation is, in essence, a group of studies conducted to test the hypotheses forming the conceptual site model and turning qualitative descriptions into quantitative descriptions. The initial conceptual model should be modified to document additional source, pathway, and contaminant information that is collected throughout the site investigation. Project managers should also be aware of the spatial and temporal dimensions to the processes depicted in a CSM. Although these are difficult to represent in static graphical form, it is important to consider the relevance and role of these dimensions when using the CSM and developing hypotheses or inferences from them.

A good CSM can be a valuable tool in evaluating the potential effectiveness of remedial alternatives. As noted in the following section on risk assessment, the CSM should capture in one place the pathways remedial actions are designed to interdict to reduce exposure of human and ecological receptors to contaminants. Typical elements of a CSM for a sediment site are listed in Highlight 2-2.

Project managers may find it useful to develop several conceptual site models that highlight different aspects of the site. At complex sediment sites, often three conceptual site models are developed: 1) sources, release and media, 2)human health, and 3) ecological receptors. For sites with more than one contaminant that are driving the risks, especially if they behave differently in the environment (e.g., PCBs vs. metals), it is often useful to develop a separate CSM for different contaminants or groups of contaminants. Highlight 2-3, Highlight 2-4, and Highlight 2-5 present examples that focus on ecological and human health threats.

Highlight 2-2: Typical Elements of a Conceptual Site Model for Sediment	
Sources of Contaminants of Concern: • Upland soils • Floodplain soils • Surface water • Ground water • Non-aqueous phase liquids (NAPL) and other source materials • Sediment "hot spots" • Outfalls, including combined sewer outfalls and storm water runoff outfalls • Atmospheric contaminants	Exposure Pathways for Humans: • Fish/shellfish ingestion • Dermal uptake from wading, swimming • Water ingestion • Inhalation of volatiles Exposure Pathways for Biota: • Fish/shellfish/benthic invertebrate ingestion • Incidental ingestion of sediment • Direct uptake from water
Contaminant Transport Pathways: • Sediment resuspension • Surface water transport • Runoff • Bank erosion • Ground water advection • Bioturbation • Food chain	Human Receptors: • Recreational fishers • Subsistence fishers • Waders/swimmers/birdwatchers • Workers and transients Ecological Receptors: • Benthic/epibenthic invertebrates • Bottom-dwelling/pelagic fish • Mammals and birds (e.g., mink, otter, heron, bald eagle)

2.3 RISK ASSESSMENT

Consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), a human health risk assessment and an ecological risk assessment should be performed at all contaminated sediment sites. In addition to assessing risks due to contaminated sediment, in many cases, risks from soil, surface water, ground water and air pathways may need to be evaluated as well. One of the outputs from the risk assessment should be an understanding of the relative importance or contribution of the pathways depicted in the conceptual site model to actual risk. This understanding is generally key to making informed decisions about which remedial alternative to implement at a site.

Generally, the human health risk assessment should consider the cancer risks and non-cancer health hazards associated with ingestion of fish and other biota inherent to the site (e.g., shellfish, ducks); dermal contact with and incidental ingestion of contaminated sediment; inhalation of volatilized contaminants; swimming; and possible ingestion of river water if it is used as a drinking water supply. Separate analyses should also consider risks from exposure to floodplain soils and may include direct contact, ingestion, and exposures to homegrown crops, beef, and dairy products where appropriate. The relevance and importance of each pathway to actual risks will vary with different contaminants or contaminant classes at a site. In addition, the risk assessment should include an analysis of the risks that may be introduced due to implementation of remedial alternatives (see Section 2.3.3, Risks from Remedial Alternatives). As with all remedial investigation (RI) and feasibility study (FS) data collection efforts, the scope of the assessments should be tailored to the complexity of the site and how much information is needed to reach and support a risk management decision. It is important to involve the risk assessors early in the process to ensure that the information collected is appropriate for use in the risk assessment.

Screening and baseline risk assessments are designed to evaluate the potential threat to human health and the environment in the absence of any remedial action. Generally, they provide the basis for determining whether remedial action is necessary as well as the framework for developing risk-based remediation goals. Risk assessments should also provide information to evaluate risks associated with implementing various remedial alternatives that may be considered for the site. Detailed guidance on performing human health risk assessments is provided in a number of documents, available through EPA's Superfund Risk Assessment Web site at http://www.epa.gov/oswer/riskassessment/risk_superfund.htm. The *Risk Assessment Guidance for Superfund* (U.S. EPA 1989, also referred to as "RAGS"), provides a basic plan for developing human health risk assessments. Specific guidance on the standardized planning, reporting, and review of risk assessments is available at http://www.epa.gov/oswer/riskassessment/ragsd/index.htm.

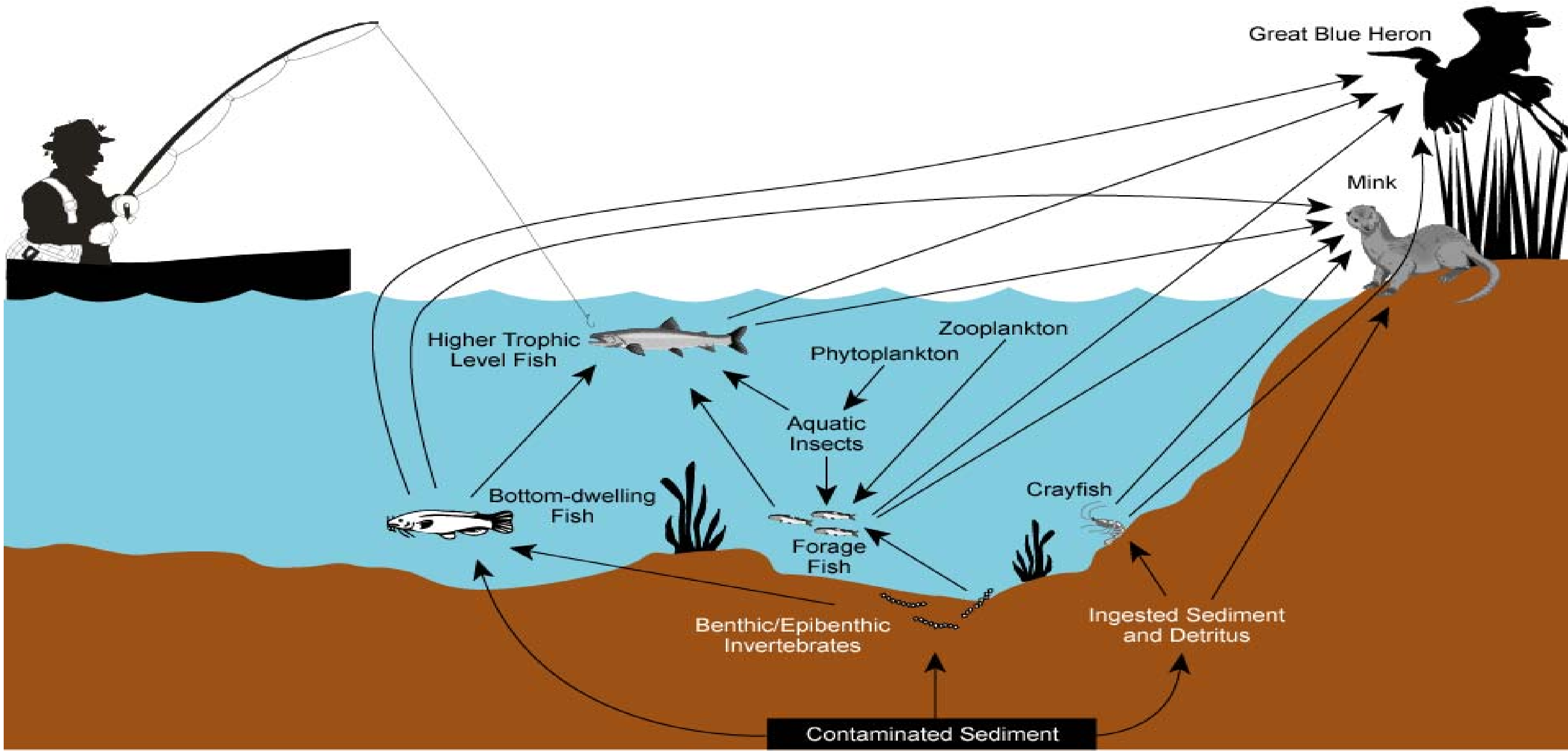
Detailed guidance on performing ecological risk assessments is provided in *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment* (U.S. EPA 1997d, also referred to as "ERAGS"). In addition, OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* (U.S. EPA 1999b), provides risk managers with several principles to consider when making ecological risk management decisions. As stated in the *Role of the Ecological Risk Assessment in the Baseline Risk Assessment* (U.S. EPA 1994b), the purpose of the ecological risk assessment is to 1) identify and characterize the current and potential threats to the environment from a hazardous substance release, 2) evaluate the ecological impacts of alternative remediation strategies, and 3) establish cleanup levels in the selected remedy that will protect those natural resources at risk.

Although not EPA guidance, project managers may find useful the Navy guidance *Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities*, which provides information on performing human health and ecological risk assessments at contaminated sediment sites [U.S. Naval Facilities Engineering Command (FEC) 2003].

2.3.1 Screening Risk Assessment

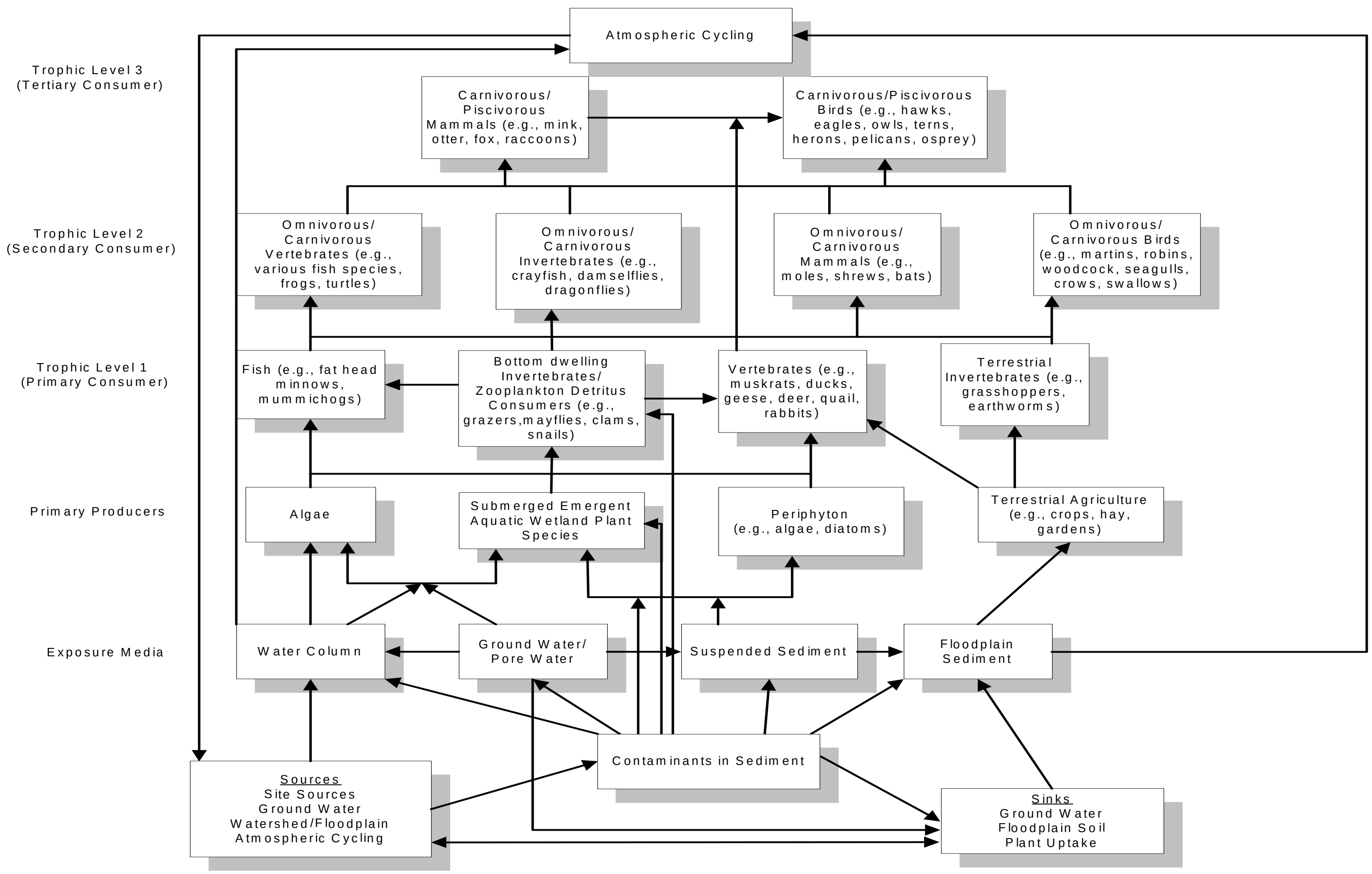
A screening risk assessment typically is performed to identify the contaminants of potential concern (COPCs) and the portions of a site that may present an unacceptable risk to human health or the environment. Currently, there are no widely accepted sediment screening values for human health risk from either direct contact with sediment or from eating fish or shellfish, although research is ongoing. For floodplain and beach soils, human health soil screening levels may be used. Widely accepted screening values do exist for ecological risk from direct toxicity, although, similar to the situation for human health risk, screening values for risk to wildlife and fish from bioaccumulative contaminants have not yet been fully developed. Each of these issues is discussed further below. In cases where screening levels do exist, or may be developed in the future, it is very important for project managers to keep in mind that screening values are not designed to be used as default cleanup levels and generally should not be used for that purpose. In evaluating whether specific screening values are appropriate for a particular site, project managers should consider whether the source of the data used to develop the screening values are relevant to site conditions, and understand the methods by which the screening values were derived. Project managers may also find ecological screening values or human health screening level exposure assumptions useful for evaluating whether detection levels for sediment analytical work are sufficiently low to be useful for risk assessment.

Highlight 2-3: Sample Pictorial-Style Conceptual Site Model Focusing on Human and Ecological Threats

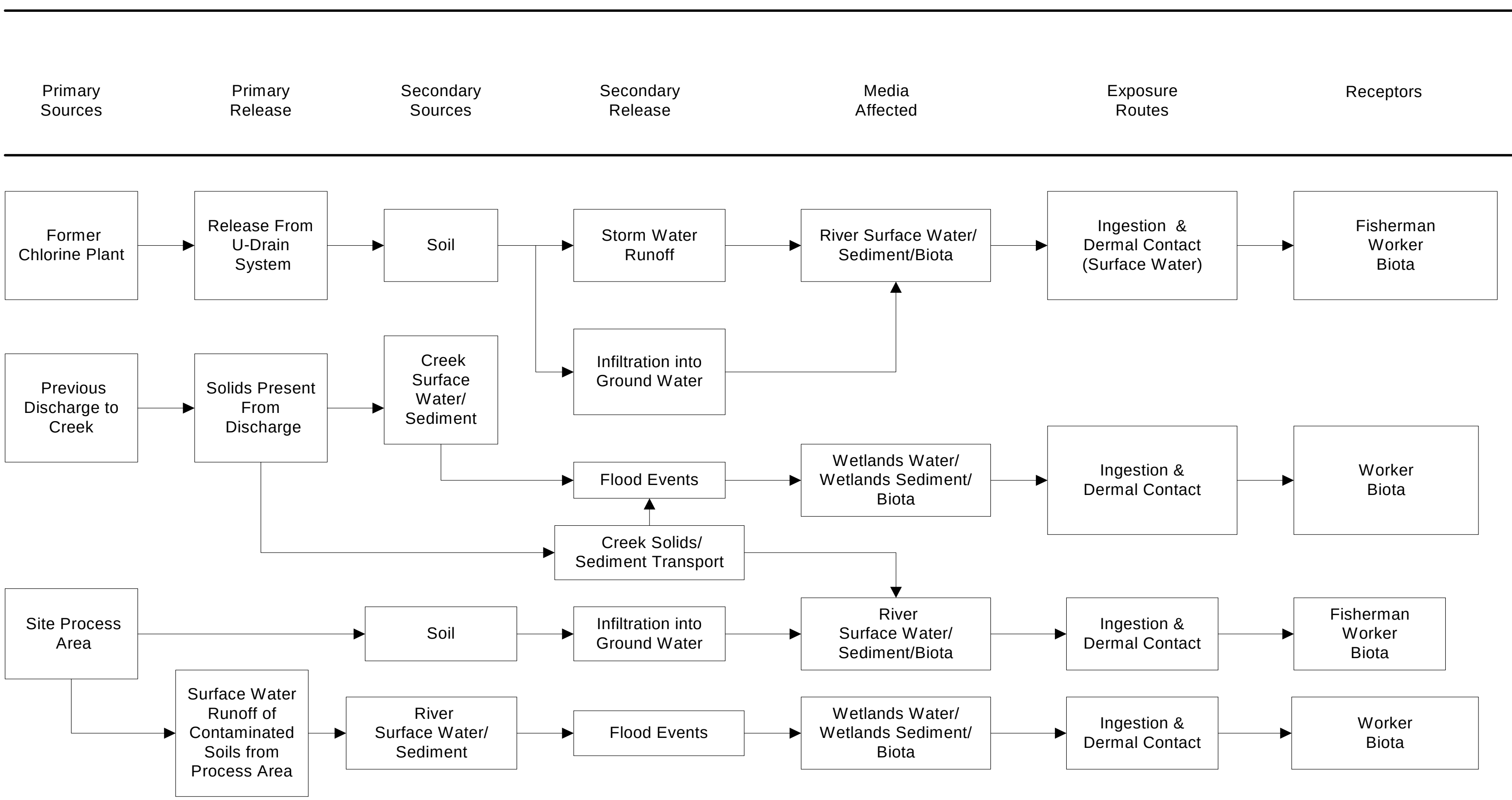


Source: Adapted from EPA Region 5, Sheboygan Harbor and River Site

Highlight 2-4: Sample Conceptual Site Model Focusing on Ecological Threats



Highlight 2-5: Sample Conceptual Site Model Focusing on Human Health Threats



When evaluating human health risks from direct contact with sediments and from bioaccumulative contaminants in fish and shellfish, RAGS (U.S. EPA 1989), and other risk guidance discussed above, should be followed to identify the COPCs that may present an unacceptable risk. In general, if bioaccumulative contaminants are found in biota at levels above site background, they should not be screened out and should be carried into the baseline risk assessment.

When evaluating human health risks from direct contact with floodplain or beach soils, OSWER and several regions have soil screening values that may be useful. Human health soil screening levels (SSLs) for residential and industrial properties are available through EPA's Superfund Web site at http://www.epa.gov/superfund/resources/soil, which provide a generic approach and exposure assumptions for evaluation of risks from direct contact with soil.

When screening ecological risk to benthic biota from direct toxicity, project managers should consult EPA's Eco-Updates *EcoTox Thresholds* (U.S. EPA 1996c) and *The Role of Screening-Level Risk Assessment and Refining Contaminants of Concern in Baseline Ecological Risk Assessments* (U.S. EPA 2001f), which describes the process of screening COPCs. The EPA's equilibrium-partitioning sediment benchmarks are available at http://www.epa.gov/nheerl/publications/, and the Superfund program's Ecotox Thresholds (ETs) are available at http://www.epa.gov/oswer/riskassessment/pdf/eco_updt.pdf can be used as screening values for risk to benthic biota from direct toxicity. Other published sediment guidelines [e.g., National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRTs), http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html] can also be used as screening values. Table 3-1 in the Navy guidance (U.S. Navy FEC 2003) also provides a list of citations for ecological screening values for sediment.

When screening ecological risks to terrestrial receptors from contaminated floodplain soils, the OSWER Directive 9285.7-55, *Guidance for Developing Ecological Soil Screening Levels* [(Eco-SSLs), U.S. EPA 2003c, http://www.epa.gov/oswer/riskassessment/ecorisk/ecossl.htm] should be used. Eco-SSLs for some receptors have been developed for aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, dieldrin, iron, lead, manganese, nickel, pentachlorophenol, selenium, trinitrotoluene (TNT), and zinc. Screening values for dichloro diphenyl trichlorethane (DDT), polycyclic aromatic hydrocarbons (PAHs), silver, and vanadium are currently under development.

For ecological risk to wildlife or fish from food chain effects, widely accepted screening values have not yet been fully developed. As for the human health risk assessment, if bioaccumulative contaminants are found in biota at levels above site background, they generally should not be screened out and should be carried into the baseline risk assessment for ecological risk as well.

2.3.2 Baseline Risk Assessment

At contaminated sediment sites with bioaccumulative contaminants, the human health exposure pathway driving the risk is usually ingestion of biota, most commonly the ingestion of fish by recreational anglers and sometimes by subsistence anglers. However, depending on the contaminant and the use of the site there can also be significant risks from direct contact with the sediment, water, or floodplain soils, through incidental ingestion and dermal contact.

Generally, the ecological risk assessment should consider the risks to invertebrates, plants, fish and wildlife from direct exposure and from food chain expsoures. The selection of appropriate site-specific assessment endpoints is a critical component of the ecological risk assessment. Once assessment endpoints have been selected, testable hypotheses and measurement endpoints can be developed to evaluate the potential threat of the contaminants of potential concern to the assessment endpoints. PCBs, for example, bioaccumulate in food chains and can diminish reproductive success in upper trophic level species (e.g., mink, kingfishers) exposed to contaminants through their diet. Therefore, reduced reproductive success in fish-eating birds and mammals may be an appropriate assessment endpoint. An appropriate measurement endpoint in this case might be contaminant concentrations in fish or in the sediment where the concentrations in these media can be related to reproductive effects in the top predator that eats the fish. The sediment concentration range associated with an acceptable level of reproductive success usually would constitute the remediation goal.

2.3.3 Risks from Remedial Alternatives

Although significant attention has been paid to evaluating baseline risks, traditionally less emphasis has been placed on evaluating risks from remedial alternatives, in part because these risks may be difficult to quantify. In 1991, the EPA issued a supplement to the RAGS Guidance, *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Part C, Risk Evaluation of Remedial Alternatives* (U.S. EPA 1991a). Although the 1991 guidance addresses only human health risks, it does note that remedial actions, by their nature, can alter or destroy aquatic and terrestrial habitat, and advises that this potential for destruction or alteration of habitat and subsequent consequences be evaluated and considered during the selection and implementation of a remedial alternative.

The short-term and long-term risks to human health and the environment that may be introduced by implementing each of the remedial alternatives should be estimated and considered in the remedy selection process. Generally, the types, magnitude, and time frames of risk associated with each alternative is extremely site specific. Increases to current risks and the creation of new exposure pathways and risk should be considered.

Implementing a MNR remedy should cause no increase in baseline risks and no creation of new risks, although existing risks may change due to disturbance or significant watershed changes. Implementing in-situ capping might result in increased risk of exposure to contaminants released to the surface water during capping; other community impacts (e.g., accidents, noise, residential or commercial disruption; worker exposure during transport of cap materials and cap placement; and disruption of the benthic community. Existing risks of exposure to contaminants may also occur if contaminants are released through the cap. Implementing dredging or excavation might result in increased risk of exposure to contaminants released during sediment removal, transport, or disposal; other community impacts (e.g., accidents, noise, residential or commercial disruption); worker exposure during sediment removal and handling; and disruption of the benthic community. Risks of exposure to contaminants in residual contamination may also occur. Each of these risks or potential exposure pathways may exist for different periods of time; some are relatively short-lived, while others may exist for a longer period of time. The analysis of risk from implementation of various alternatives is important for remedy selection, and is discussed in more detail in the remedy-specific chapters of this guidance and in Chapter 7, Section 7.4, Comparing Net Risk Reduction.

2.4 CLEANUP GOALS

In selecting the most appropriate remedy for a site, usually it is important to develop clearly defined remedial action objectives (RAOs) and contaminant-specific remediation goals (RGs). RAOs are generally used in developing and comparing alternatives for a site and in providing the basis for developing more specific RGs, which in turn are used by project managers to select final sediment cleanup levels based on the other NCP remedy selection criteria. RAOs, RGs, and cleanup levels are normally dependent on each other and represent three steps along a continuum leading from RI/FS scoping to the selection of a remedial action that will be protective of human health and the environment, meet applicable or relevant and appropriate requirements (ARARs), and provide the best balance among the remaining NCP criteria. Under CERCLA, RAOs and cleanup levels generally are final when the record of decision (ROD) is signed. Where the site is not available for unlimited access and unrestricted use, their protectiveness is reviewed every five years.

2.4.1 Remedial Action Objectives and Remediation Goals

RAOs are intended to provide a general description of what the cleanup is expected to accomplish, and help focus the development of the remedial alternatives in the feasibility study. RAOs are typically derived from the conceptual site model (Section 2.2), and address the significant exposure pathways. RAOs may vary widely for different parts of the site based on the exposure pathways and receptors, regardless of whether these parts of the site are managed separately as operable units under CERCLA. For example, a sediment site may include a recreational area used by fishermen and children, as well as a wetland that provides critical habitat for fish and wildlife. Though both areas may contain similarly contaminated sediment, the different receptors and exposure pathways may lead a project manager to develop different RAOs and RGs for each area that are protective of the different receptors.

The development of RAOs should also include a discussion of how they address all the unacceptable human health and ecological risks identified in the risk assessment. Examples of RAOs specific for sediment sites are included in Highlight 2-6. Sediment sites also may need RAOs for other media (e.g., soils, ground water, or surface water). When developing RAOs, project managers should evaluate whether the RAO is achievable by remediation of the site or if it requires additional actions outside the control of the project manager. For example, complete biota recovery may depend on the cleanup of sources that are regulated under other authorities. The project manager may discuss these other actions in the ROD and explain how the site remediation is expected to contribute to meeting area-wide goals outside the scope of the site, such as goals related to watershed concerns, but RAOs should reflect objectives that are achievable from the site cleanup.

Generally, preliminary remediation goals (PRGs) that are protective of human health and the environment are developed early in the remedial investigation process based on readily available screening levels for both human health and ecological risks (although project managers should be aware that currently available screening levels for sediment may be limited; see Section 2.3.1).

Highlight 2-6: Sample Remedial Action Objectives for Contaminated Sediment Sites

Human Health:

- Reduce to acceptable levels the risks to children and adults from the incidental ingestion of and dermal exposure to contaminated sediment while playing, wading, or swimming at the site

- Reduce to acceptable levels the risks to adults and children from ingestion of contaminated fish and shellfish taken from the site

Ecological Risk:

- Reduce to acceptable levels the toxicity to benthic aquatic organisms at the site to levels

- Reduce to acceptable levels the risks to birds and mammals that feed on fish that have been contaminated from sediment at the site

As more information is generated during the investigation, these PRGs should be replaced with site-specific RGs by incorporating an improved understanding of site conditions (e.g., site-specific information on fish ingestion rates and bioaccumulation of contaminants in sediment into biota; resource use; other human activities), and other site-specific factors, such as the bioavailability of contaminants. The human health and ecological risk assessors should identify appropriate RGs for each contaminant of concern in each medium of significance. RGs for sediment often address direct contact for humans and biota to the sediment as well as bioaccumulation through the food chain. The concentrations of bioaccumulative contaminants in fish typically are a function of both the sediment and water concentrations of the contaminant, and are, to some extent, species-dependent. The development of the sediment RGs may involve a variety of different approaches that range from the simple application of a bioaccumulation factor from sediment to fish or more sophisticated food chain modeling. The method used and the level of complexity in the back calculation from fish to sediment should be consistent with the approaches used in the human health and ecological risk assessments.

RGs should be represented as a range of values within acceptable risk levels so that the project manager may consider the other NCP criteria when selecting the final cleanup levels. For human health, general guidance is available regarding the exposure equations necessary to develop RG concentrations in various media for both cancer risks and non-cancer health hazards (see Section 2.3.) The development of the human health-based RGs should provide a range of risk levels (e.g., 10^{-6}, 10^{-5}, and 10^{-4} and a non-cancer Hazard Index of 1 or less depending on the health end points of the specific contaminants of concern.) The development of the ecologically based RGs should also provide a range of risk levels based on the receptors of concern identified in the ecological risk assessment (see Section 2.3). Human health and ecological RGs should be developed through iterative discussions between the project manager, risk assessor, and modeler or other appropriate members of the team.

2.4.2 Cleanup Levels

At most CERCLA sites, RGs for human health and ecological receptors are developed into final, chemical-specific, sediment cleanup levels by weighing a number of factors, including site-specific uncertainty factors and the criteria for remedy selection found in the NCP at Title 40 Code of Federal Regulations (40 CFR) §300.430. These criteria include long-term effectiveness and permanence;

reduction of toxicity, mobility and volume through treatment; short-term effectiveness; implementability; cost; and state and community acceptance. Chapter 3, Section 3.2, NCP Remedy Selection Criteria discusses these criterion in detail. Regions should note, however, that some states do have chemical and/or biological standards for contaminated sediment (e.g., in development by the State of Washington and others) that may be ARARs at sediment sites.

Uncertainty factors that may be relevant to consider include (among others) the reliability of inputs and outputs of any model used to estimate risks and establish cleanup levels, reliability of the potential approaches to achieve those results, and the likelihood of occurrence for the exposure scenarios being considered. Other technical factors include (among others) limitations of remedial alternatives and detection and quantification limits of contaminants in environmental media. It is especially important to consider both background levels of contamination and what has been achieved at similar sites elsewhere, so that achievable cleanup levels are developed. All of these factors should be considered when establishing final cleanup levels that are within the risk range.

The derivation of ecologically based cleanup levels is a complex and interactive process incorporating contaminant fate and transport processes, toxicological considerations and potential habitat impacts of the remediation alternatives. Before selecting a cleanup level, the project manager, in consultation with the ecological risk assessor, should consider at least the following factors (U.S. EPA 1999b):

- The magnitude of the observed or expected effects of site releases and the level of biological organization affected (e.g., individual, local population, or community);

- The likelihood that these effects will occur or continue;

- The ecological relationship of the affected area to the surrounding habitat;

- Whether the affected area is a highly sensitive or ecologically unique environment; and

- The recovery potential of the affected ecological receptors and expected persistence of the chemicals of concern under present site conditions.

Generally, for CERCLA actions, the ROD should include chemical-specific cleanup levels as provided in the NCP at 40 CFR §300.430(c)(2)(I)(A). The ROD should also indicate the approach that will be used to measure attainment of the cleanup levels and how cleanup levels relate to risk reduction. At many sediment sites, especially but not exclusively those with bioaccumulative contaminants, the attainment of sediment cleanup levels may not coincide with the attainment of RAOs. For example, this may be due to the length of time needed for fish or the benthic community to recover. Where cleanup levels have been achieved but progress towards meeting RAOs is not as expected, the five-year review process, or where appropriate, a similar process conducted before five years, should be used to assess whether additional actions are needed. Consistent with the NCP (40 CFR §300.430(f)(4)(ii)), where contaminants remain present above unlimited use and unrestricted exposure levels, Superfund sites should be reviewed no less than every five years after initiation of the selected remedial action. Chapter 8, Remedial Action and Long-Term Monitoring, provides additional guidance on the information that should be collected for this review to be effective. As explained further in Chapter 8, the need for long-term monitoring is not limited to sites where five-year reviews are required. Most sites where contaminated sediment has been removed also should be monitored for some period to ensure that cleanup levels and RAOs are met and will continue to be met.

2.5 WATERSHED CONSIDERATIONS

A unique aspect of contaminated sediment sites is their relationship within the overall watershed, or drainage area, in which they are located. Within the watershed there often is a spectrum of issues that the project manager may need to consider. Foremost among them at many sites is to work with the state to ensure that fish consumption advisories are in place and well publicized. In addition, project managers should understand the role of the contaminated water body in the watershed, including the habitat or flood control functions it may serve, the presence of non-site-related contaminant sources in the watershed, and current and reasonably anticipated or desired future uses of the water body and surrounding land.

2.5.1 Role of the Contaminated Water Body

Most water bodies provide important habitat for spawning, migration, or food production for fish, shellfish, birds, and other aquatic and land-based animals. One significant issue is the protection of migratory fish. These are fish such as salmon, shad, and herring that migrate as adults from marine waters up estuaries and rivers to streams and lakes where they spawn. The juveniles spend varying lengths of time in freshwater before migrating to estuarine/marine waters. It can be difficult to evaluate the impact of a particular contaminated sediment site on wide-ranging species that may encounter several sources of contamination along their migratory route. This can be an important consideration when evaluating alternatives and establishing remediation goals for a site, as these fish populations may not show improvement if any link in their migratory route is missing, blocked, or toxic. For migratory species, it may be more appropriate to measure risk and remedy effectiveness in terms of risk to juveniles, or whatever part of the life cycle is spent at the site.

The size, topography, climate, and land use of a watershed, among other factors, may affect characteristics of a water body, such as water quality, sedimentation rate, sediment characteristics, seasonal water flows and current velocities, and the potential for ice formation. For example, watersheds with large wetland areas tend to store flood waters and enable ground water recharge, thereby protecting downstream areas from increased flooding, whereas an agricultural or urbanized watershed may have increased erosion and greater flow during storm events. Watershed changes can result from natural events, such as wildfires, or from human activities such as road and dam construction/removal, impoundment releases, and urban/suburban development. When considering watershed characteristics, it is generally important to consider both current and future watershed conditions.

Some sediment sites are located in watersheds with a large number of historical and ongoing point and non-point sources, from many potentially responsible parties. Where this is the case, it can be especially important to attain expert assistance to plan site characterization strategies that are well suited to the complexity of the issues and designed to answer specific questions. In urban watersheds and others with a large number of ongoing sources, it may be beneficial for a broader group of stakeholders to participate in setting priorities for site characterization and remediation efforts. In these areas, it can be especially important to consider background concentrations when developing remedial objectives and to evaluate the incremental improvement to the environment if an action is taken at a specific site in the watershed. Approaching management of a site within the watershed context may provide an opportunity to better determine the needs and coordinate the sequence and schedule of cleanup activities in the watershed.

2.5.2 Water Body and Land Uses

Water body uses at sediment sites may include commercial navigation; commercial fisheries, shellfisheries, or aquaculture; boating, swimming, and other forms of recreation; other commercial or industrial uses; recreational or subsistence fishing or shellfishing; and other, less easily categorized uses. Most water bodies used for commercial navigation, such as for shipping channels, turning basins, and port areas, are periodically dredged to conform to the minimum depth for the area prescribed by Congress; such dredging is typically performed or permitted by the U.S. Army Corps of Engineers (USACE). Other commercial or industrial uses of a site may include the presence of gravel pits, drinking water use, and industrial uses of water including cooling, washing, or waste water disposal.

The NCP preamble (55 *FR* 8710) states that both current and future land uses should be evaluated in assessing risks posed by contaminants at a Superfund site and discusses how Superfund remedies should be protective in light of reasonably anticipated future uses. EPA has provided further guidance on how to evaluate future land use in the OSWER Directive 9355.7-04, *Land Use in the CERCLA Remedy Selection Process* (U.S. EPA 1995a, also referred to as the "Land Use Guidance"). This guidance encourages early discussions with state and local land use planning authorities and the public, regarding reasonably anticipated future uses of properties associated with a National Priorities List (NPL) site. This coordination should begin during the scoping phase of the RI/FS, and ongoing coordination is recommended to ensure that any changes in expectations are incorporated into the remedial process.

There are additional factors the project manager should include in considering anticipated future uses for aquatic sites not specifically addressed in the Land Use Guidance. For example, future use of the site by ecological receptors may be a more important consideration for an aquatic sediment Superfund or RCRA site as compared to an upland terrestrial site. A remediated sediment site may attract more recreational, subsistence, and cultural uses, including fishing, swimming, and boating. Where applicable, the project manager should consider tribal treaty rights to collect fish or other aquatic resources. The project manager should also consider [generally as TBCs (or to be considered), see Chapter 3, Section 3.3 on ARARs] designated uses in the state's water quality standards, priorities established as a result of total maximum daily loads (TMDLs), or pollution reduction efforts under various Clean Water Act (CWA) programs in projecting future waterway uses. In ports and harbors, the project manager should consult master plans developed by port and harbor authorities for projections of future use. The USACE should also be contacted regarding future navigational dredging of federally maintained channels.

There may be more parties to consult about anticipated future use at large sediment sites as opposed to typical upland sites. These parties include the community, environmental groups, natural resource trustees, Indian tribes, the local department of health, as well as local government, port and harbor authorities, and land use planning authorities. As with upland sites, consultation should start at the RI/FS scoping phase and continue throughout the life of the project. Different stakeholders often have divergent and conflicting ideas about future use at the site. Local residents and environmental groups may anticipate future habitat restoration and increased recreational and ecological use while local industrial landowners may project increased shipping and industrial use. The NCP preamble (55 *FR* 8710) states that, in the baseline risk assessment, more than one future use assumption should be considered when decision makers wish to understand the implications of different exposure scenarios.

Especially where there is some uncertainty regarding the anticipated future uses, the project manager should compare the potential risks associated with several use scenarios.

The identification of appropriate future use assumptions during the baseline risk assessment and the feasibility study should allow the project manager to focus on developing protective, practicable, and cost-effective remedial alternatives. In addition, coordination with stakeholders on land and water body uses leads to opportunities to coordinate Superfund or RCRA remediation in conjunction with local development or habitat restoration projects. For example, at some sites the EPA has worked with port authorities to combine Superfund or RCRA remedial dredging with dredging needed for navigation. Others have combined capping needed for Superfund or RCRA remediation with habitat restoration, allowing PRPs to settle natural resource damage claims in conjunction with the cleanup. However, as noted in Chapter 1, Section 1.5, State, Tribal, and Trustee Involvement, whether remediation and restoration are addressed concurrently is a site-specific decision that involves input from a number of different parties.

2.6 SOURCE CONTROL

Identifying and controlling contaminant sources typically is critical to the effectiveness of any Superfund sediment cleanup. Source control generally is defined for the purposes of this guidance as those efforts are taken to eliminate or reduce, to the extent practicable, the release of contaminants from direct and indirect continuing sources to the water body under investigation. At some sediment sites, the original sources of the contamination have already been controlled, but subsequent sources such as contaminated floodplain soils, storm water discharges, and seeps of ground water or non-aqueous phase liquids (NAPLs) may continue to introduce contamination to a site. At sites with significant sediment mobility, areas of higher contaminant concentration may act as continuing sources for less-contaminated areas.

Some sources, especially those outside the boundaries of the Superfund or RCRA site, may best be handled under another authority, such as the CWA or a state program. These types of sites can present an opportunity for partnering with private industry and other governmental entities to identify and control sources on a watershed basis. Water bodies with sources outside the Superfund site can also present a need to balance the desire for watershed-wide solutions with practical considerations affecting a subset of responsible parties. It can be difficult to determine the proper party to investigate sources outside the Superfund site, but the site RI/FS must be sufficient to determine the extent of contamination coming onto the site and its likely effect on any actions at the site. A critical question often is whether an action in one part of the watershed is likely to result in significant and lasting risk reduction, given the probable timetable for other actions in the watershed.

Source control activities are often broad-ranging in scope. Source control may include application of regulatory mechanisms and remedial technologies to be implemented according to ARARs, including the application of technology-based and water quality-based National Pollutant Discharge Elimination System (NPDES) permitting to achieve and maintain sediment cleanup levels. Source control actions may include, among others, the following:

- Elimination or treatment of contaminated waste water or ground water discharges (e.g., installing additional treatment systems prior to discharge);

- Isolation or containment of sources (e.g., capping of contaminated soil) with attendant engineering controls;

- Pollutant load reductions of point and nonpoint sources based on a TMDL;

- Implementation of best management practices (e.g., reducing chemical releases to a storm drain line); and

- Removal or containment of potentially mobile sediment hot spots.

EPA's Contaminated Sediment Management Strategy (U.S. EPA 1998a) includes some discussion of EPA's strategy for abating and controlling sources of sediment contamination. Source control activities may be implemented by state or local governments using combinations of voluntary and mandatory actions.

The identification of continuing sources and an evaluation of their potential to re-contaminate site sediment are often essential parts of site characterization and the development of an accurate conceptual site model, regardless of source areas within the site. When there are multiple sources, it is often important to prioritize sources to determine the relative significance of continuing sources versus on-site sediment in terms of site risks to determine where to focus resources. Where sources are a part of the site, project managers should develop a source control strategy or approach for the site as early as possible during site characterization. Where sources are outside the site, project managers should encourage the development of source control strategies by other authorities, and understand those strategies. Generally, a source control strategy should include plans for identifying, characterizing, prioritizing, and tracking source control actions, and for evaluating the effectiveness of those actions. It is also useful to establish milestones for source control that can be linked with sediment remedial design and cleanup actions. If sources can be substantially controlled, it is normally very important to reevaluate risk pathways to see if sediment actions are still needed. If sources cannot be substantially controlled, it is typically very important to include these ongoing sources in the evaluation of what sediment actions may or may not be appropriate and what RAOs are achievable for the site.

Generally, significant continuing upland sources (including ground water, NAPL, or upgradient water releases) should be controlled to the greatest extent possible before sediment cleanup. Once these sources are controlled, project managers should evaluate the effectiveness of the actions, and should refine and adjust levels of source control, as warranted. In most cases, before any sediment action is taken, project managers should consider the potential for recontamination and factor that potential into the remedy selection process. If a site includes a source that could result in significant recontamination, source control measures will be likely necessary as part of that response action. However, where sediment remediation is likely to yield significant benefits to human health and/or the environment after considering the risks caused by an unaddressed or ongoing source, it may be appropriate to conduct an action for sediment prior to completing all land-based source control actions.

2.7 PHASED APPROACHES, ADAPTIVE MANAGEMENT, AND EARLY ACTIONS

At some sediment sites, a phased approach to site characterization, remedy selection, or remedy implementation may be the best or only practical option. Phasing site characterization can be especially useful when risks are high, yet some important site-specific factors are unknown. Phasing in remedy selection and implementation may be especially useful at sites where contaminant fate and transport processes are not well understood or the remedy has significant implementation uncertainties. Phasing may also be useful where the effectiveness of source control is in doubt. By knowing the effectiveness of source control prior to implementing sediment cleanups, the risk of having to revisit recontaminated areas is greatly reduced. High remedy costs, the lack of available services and/or equipment, and uncertainties about the potential effectiveness or the risks of implementing the preferred sediment management approach, can also lead to a decision to phase the cleanup. At some sites, it may be advantageous to pilot less invasive or less costly remedial alternatives early enough in the process that performance could be tracked. If performance does not approach desired levels, then more invasive or more costly approaches could be pursued.

Phasing can also be used at large, multi-source, multi-PRP sites with primarily historic contamination where contaminated sediment is still near the sources. At these types of sites, working with a single responsible party to address sediment with higher contaminant concentrations near a specific source may be an effective risk reduction measure, while the more complex decision making for the rest of the site is ongoing.

Project managers are encouraged to use an adaptive management approach, especially at complex sediment sites to provide additional certainty of information to support decisions. In general, this means testing of hypotheses and conclusions and reevaluating site assumptions as new information is gathered. This is an important component of updating the conceptual site model. For example, an adaptive management approach might include gathering and evaluating multiple data sets or pilot testing to determine the effectiveness of various remedial technologies at a site. The extent to which adaptation is cost-effective is, of course, a site-specific decision. Resources on adaptive management at sediment sites include the NRC's report *Environmental Cleanup at Navy Facilities* (NRC 2003) and Connolly and Logan (2004).

Even before the sediment at a site is well characterized, if risk is obvious, it may be very important to begin to control significant ongoing land-based sources. It also may be appropriate to take other early or interim actions, followed by a period of monitoring, before deciding on a final remedy. Highlight 2-7 provides examples of early actions taken to control sources, minimize human exposure, control sediment migration, or reduce risk from sediment hot spots at contaminated sediment sites. Early or interim actions are frequently used to prevent human exposure to contaminants or to control sources of sediment contamination. However, such actions for sediment are less frequent. Factors for determining which response components may be suitable for early or interim actions include the time frame needed to attain specific objectives, the relative urgency posed by potential or actual exposure, the degree to which an action may reduce site risks, and compatibility with likely long-term actions (U.S. EPA 1992b).

An early action taken under Superfund removal authority may be appropriate at a sediment site when, for example, it is necessary to respond quickly to a release or a threatened release of a hazardous substance that would present an immediate threat. At contaminated sediment sites, removal authority or state authorities have been used to implement many of the actions listed in Highlight 2-7. The NCP at 40 CFR §300.415 outlines criteria for using removal authority, as further explained in the EPA guidance and directives (U.S. EPA 1993a, U.S. EPA 1996d, U.S. EPA 2000d). Project managers may also consider separating the management of source areas from other, less concentrated areas by establishing separate operable units (OUs) for the site.

2.8 SEDIMENT AND CONTAMINANT FATE AND TRANSPORT

An important part of the remedial investigation at many sediment sites is an assessment of the extent of sediment and contaminant transport and the effect of that transport on exposure and risk. This usually includes gaining an understanding of the processes and events in the past and predicting future transport and exposure.

Highlight 2-7: Potential Examples of Early Actions at Contaminated Sediment Sites

Actions to prevent releases of contaminants from sources:

- Excavation or containment of floodplain soils or other source materials in the floodplain
- Engineering controls (e.g., sheet pilings, slurry walls, grout curtains, and extraction) to prevent highly contaminated ground water, NAPL, or leachate from reaching surface water and sediment
- Engineering controls to prevent contaminated runoff from reaching surface water and sediment

Actions to minimize human exposure to contaminants (coordinated with other appropriate agencies):

- Access restrictions
- Fish consumption advisories
- Use restrictions and advisories for water bodies
- Actions to protect downstream drinking water supplies

Actions to minimize further migration of contaminated sediment:

- Boating controls (e.g., vessel draft or wake restrictions to prevent propeller wash, anchoring restrictions)
- Excavating, dredging, capping, or otherwise isolating contaminated sediment hot spots

Actions taken to reduce risk from highly contaminated sediment hot spots:

- Capping, excavation, or dredging of localized areas of contaminated sediment that pose a very high risk

In most aquatic environments, surface sediment and any associated contaminants move over time. The more important and more complex issue is whether movement of contaminated sediment (surface and subsurface), or of contaminants alone, is occurring or may occur at scales and rates that will significantly change their current contribution to human health and ecological risk. Addressing that issue requires an understanding of the role of natural processes that counteract sediment and contaminant movement and fate, such as natural sedimentation and armoring, and contaminant transformations to less toxic or less bioavailable compounds. For this reason, it is important for project managers to use technical experts to help in the analysis, especially where large amounts of resources are at stake.

Sediment movement also is a complex topic because it has both positive and negative effects on risk. For example, floods frequently transport both clean and contaminated sediment, which are subsequently deposited within the water body and on floodplains. This may spread contamination, isolate (through burial) other existing contamination, and lower concentrations of contaminants (through dilution) within the immediate site boundaries.

Both natural and man-made (i.e., anthropogenic) forces may cause sediment and contaminants to move. Highlight 2-8 lists examples of each.

Highlight 2-8: Potential Causes of Sediment and/or Contaminant Movement

Natural causes of sediment movement include:

- Routine currents in rivers, streams, and harbors
- Tides in marine waters and estuaries
- Floods generated by rainfall or snow-melt induced runoff from land surfaces
- Ice thaw and ice dam-induced scour
- Seiches (oscillation of lake elevation caused by sustained winds), especially in the Great Lakes
- Storm-generated waves and currents (e.g., hurricanes, Pacific cyclones, nor'easters)
- Seismic-generated waves (e.g., tsunamis)
- Earthquakes, landslides, and dam failures
- Bioturbation from micro- and macrofauna

Anthropogenic causes of sediment movement include:

- Navigational dredging and channel maintenance
- Placer mining as well as sand and gravel mining
- Intentional removal or breaching of hydraulic structures such as dams, dikes, weirs, groins, and breakwaters
- In-water construction
- Boat propeller wash, ships' wakes, ship grounding or anchor dragging

Causes of dissolved contaminant movement without sediment movement include:

- Flow of ground water through sediment
- Molecular diffusion
- Gas-assisted transport

Many contaminated sediment sites are located in areas that are primarily depositional, or in areas where only a limited surface layer of sediment is routinely mobilized. In these fairly stable areas, other processes may contribute to sediment and contaminant movement and resulting exposure and risk. These include, for sediment, bioturbation, and for dissolved contaminants, ground water flow, molecular diffusion, and, potentially, gas-assisted transport. Like erosion and deposition, these processes continue to operate after remedies are in place, so an understanding of whether or not they are likely to be significant ongoing contaminant transport pathways at a particular site is especially important for evaluating in-situ capping and MNR alternatives.

Various empirical and modeling methods exist for evaluating sediment and contaminant movement and their consequences. The models normally rely upon site-specific empirical data for input parameters. Both empirical methods and models have limitations, so it is usually important to consider a variety of methods in evaluating a site and to compare the results. For large or complex sediment sites, project managers should approach an assessment of sediment and contaminant movement from the following aspects:

- A site-specific assessment of empirical site characterization data (see Section 2.8.1);
- A site-specific assessment of the frequencies and intensities of expected routine and extreme events that mobilize sediment (see Section 2.8.2);
- A site-specific assessment of ongoing processes that mobilize contaminants in otherwise stable sediment, such as bioturbation, diffusion, and advection (see Section 2.8.3); and
- A site-specific assessment of the expected consequences or results of sediment and contaminant movement in terms of exposure and risk, cost, or other consequences (see Section 2.8.4).

As noted above, this assessment will frequently require the use of models. A wide variety of models is available, ranging from simple models with small numbers of input criteria to complex, multi-dimensional models that are data intensive. A discussion of model uses and selection is presented in Section 2.9.

Especially for larger sites, a “lines of evidence” approach should be used to evaluate the extent of sediment and contaminant movement and resultant exposure for various areas of the water body. Where multiple lines of evidence point to similar conclusions, project managers may have more confidence in their predictions. Where the lines of evidence do not concur, project managers should bring their technical experts together to determine the source of the discrepancies and understand their significance. This approach is described in more detail in Chapter 4, Section 4.4, Evaluation of Natural Recovery.

2.8.1 Data Collection

An assessment of sediment and contaminant movement begins with the collection of a variety of empirical data (i.e., data derived from field or laboratory observation). Although literature values may be available for some parameters, project managers are encouraged to collect site-specific information for the most important processes at the site (as identified in the conceptual site model), especially where large resources are at stake in decision making.

The vertical and horizontal sediment and contaminant distributions present at a site are a result of all of the routine and extreme, natural and anthropogenic processes that contribute to the physical, chemical, and biological attributes of a water body. Site conditions at the time of investigation generally reflect a combination of influences. Project managers should not assume that current conditions represent stable conditions when, in fact, sediment may be actively responding to recent or current forces and events. Conversely, project managers should not assume a site or all areas of a site are unstable or contaminants are mobile at a scale or rate which significantly impacts risk. At many sites, the same areas of contamination persist over many years, despite some level of surface sediment and contaminant redistribution.

Processes that are important in terms of exposure and risk on a watershed scale may be less important in smaller, more isolated areas of a water body. Both scales of investigation may be needed. For example, in some situations, the large scale rainstorms associated with hurricanes may greatly impact sediment loading to the water body through erosion of watershed soils, but have little effect on stability of the in-water sediment bed itself. When considering the potential impacts of disruptive forces on sediment movement, it is important to assess these forces as they relate to the overall watershed and in terms of current and future site characteristics.

Many site characteristics affect sediment movement, but primary among them are the flow-induced shear stress at the bottom of the water body during various conditions, and the cohesiveness of the upper sediment layers. In most environments, bottom shear stress is controlled by currents, waves, and bottom roughness (e.g., sand ripples, biologically formed mounds in fines). A preliminary evaluation of the significance of sediment movement should include at least site-specific measurements of surface water flow velocities and discharges, water body bathymetry, and surface sediment types (e.g., by use of surface grab samples).

In some cases, empirically measured erosion rates are lower than anticipated from simple models, due to natural armoring. Winnowing (suspension and transport) of fines from the surface layers of sediment is one common form of armoring. Others are listed in Highlight 2-9, including the effect known as “dynamic armoring,” which describes the effect caused by suspended sediment or a fluff, floc, or low density mud layer (present in some estuaries and lakes) that decreases the expected erosion rate of underlying sediment.

Highlight 2-9: Principal Types of Armoring

Physical:
- Winnowing of fine grained materials, leaving larger-grained materials on surface
- Compaction of fine-grained sediment

Chemical:
- Chemical reactions and weathering of surface sediment

Dynamic:
- Suspended sediment dampening turbulence during high flow events

Biological:
- Physical protection and sequestration by rooted aquatic vegetation
- Mucous excretions of polychaetes
- Erosion-resistant fecal pellets or digested sediment

Sediment properties that affect cohesion and erosion in many sediment environments include bulk density, particle size (average and distribution), clay mineralogy, the presence of methane gas, and the organic content. It is not unusual for erosion rates to vary by 2 to 3 orders of magnitude spatially at a site, depending on currents, bathymetry, bioturbation, and other factors (e.g., pore water salinity). In a fairly uniform cohesive sediment core, erosion rates may drop several orders of magnitude with depth into the sediment bed, but in more variable cores this may not be the case.

Biological processes by macro- and microorganisms also affect sediment in multiple ways, both to increase erosion (e.g., gas generation and bioturbation by lowering bulk density) and to decrease erosion (e.g., aquatic vegetation, biochemical reactions which increase shear strength of sediment). The process of sediment mixing caused by bioturbation is discussed further in Section 2.8.3.

A wide variety of empirical methods is available to assess the extent of past sediment and contaminant movement. Highlight 2-10 lists some key examples. Each of these methods has advantages and limitations, and generally none should be used in isolation. The help of technical experts is likely to be needed to determine which methods are most likely to be useful at a particular site.

2.8.2 Routine and Extreme Events

Naturally occurring hydrodynamic forces such as those generated by wind, waves, currents, and tides, occur with great predictability and significantly influence sediment characteristics and movement (Hall 1994). While these routine forces seldom cause changes that are dramatically visible, they may be the events causing highest shear stress and, therefore, the most important factors in controlling the physical structure of a given water body. In northern climates, formation of ice dams and ice scour are also routine events that may have significant effects on sediment. It is important to note that seasonal changes in water flow may also affect where erosion and deposition occur. Depending on the location of the site, (e.g., riverine areas, coastal/marine area, inland water bodies), different water body factors will play important roles in determining sediment movement. To determine the frequency of particular routine forces acting upon sediment, project managers should obtain historical records on flows and stages from nearby gauging stations and on other hydrodynamic forces. However, project managers should keep in mind that residential or commercial development in a watershed may significantly increase the impervious area and subsequently increase the frequency and intensity of routine flood events. While the intensity of most routine forces may be low, their high frequency may cause them to be an important influence on sediment movement within some water bodies.

Highlight 2-10: Key Empirical Methods to Evaluate Sediment and Contaminant Movement

Bathymetry (evaluates net change in sediment surface elevations)

- Single point/local area devices
- Transects/cross-sections (with known vertical and horizontal accuracy)
- Longitudinal river profiles along the thalweg (i.e., location of deepest depth)
- Acoustic surveys (with known vertical and horizontal accuracy)
- Comparison to dredging records, aerial photos, overall geomorphology

Contaminant data (from continuous cores, surface sediment, and water column):

- Time-series observations (event scale and long-term seasonal, annual, decade-scale)
- Comparison of core pattern or changing pattern in surface sediment, with pollutant loading history
- Comparison of concentration patterns during and after high energy events

Sediment data (e.g., from continuous cores or surface samples):

- Patterns of grain-size distribution (McLaren and Bowles 1985, McLaren et al. 1993, Pascoe et al. 2002)
- In-situ or ex-situ erosion measurement devices [e.g., SEDFLUME (Jepsen et al. 1997, McNeil et al. 1996), PES (Tsai and Lick 1986), Sea Carousel (Maa et al. 1993), or Inverted Flume (Ravens and Gschwend 1999)]
- Sediment water interface camera

Geochronology (evaluates continuity of sedimentation and age of sediment with depth in cores):

- ^{137}Cs, lignin, stable Pb (longer-lived species to evaluate burial rate and age progression with depth)
- ^{210}Pb, ^{7}Be, ^{234}Th (shorter-lived species to evaluate depth of mixing zone)
- X-radiography, color density analysis

Geomorphological studies:

- Land and water body geometry and bathymetry; physical processes
- Human modifications

Sediment-contaminant mass balance studies, especially during high energy events:

- Upstream and tributary loadings (grain size distributions and rating curves)
- Tidal cycle sampling (in marine estuaries and coastal seas)
- Sampling during the rising limb of a rain-event generated runoff hydrograph (frequently greatest erosion)

Dissolved contaminant movement:

- Seepage meters at sediment surface
- Gradients near water body

In contrast, some water bodies are significantly affected by short-term extreme forces that are much less common. In many cases, these "extreme" forces originate by the same mechanisms as "routine" forces (e.g., wind) but are significantly stronger than routine conditions and capable of moving large amounts of sediment. Some extreme events, however, have no routine event counterparts (e.g., earthquakes). Meteorological events, such as hurricanes, may move large amounts of sediment in coastal areas due to storm surges and unusually high tides that cause flooding. Flooding may occur from snow-melt and other unusually heavy precipitation events resulting in the movement of large amounts of upland soil and erosion of sediment, which are then deposited in other areas of the water body or on floodplains when the flow slows during the falling limb of the runoff hydrograph. Scour of the sediment bed may also result from the movement of ice and/or natural or man-made debris during extreme flood events. To obtain a preliminary understanding of extreme event frequency at a site, it is important to examine both historical records (e.g., meteorological and flow records) and site characterization data (e.g., core data and bathymetry).

Floods are frequently classified by their probability of occurrence; for example 50-year, 100-year, 200-year, and probable maximum flood. Although the term "100-year flood" suggests a time frame, it is in fact a probability expression that a flood has a one percent probability of occurring (or being exceeded) in any year. Similarly, 200-year flood refers to a flood with a 0.5 percent probability of occurring in any year. Probable maximum flood refers to the most extreme flood that could theoretically occur based on maximum rainfall and maximum runoff in a watershed. It is not uncommon for multiple low probability events to happen more frequently than expected, especially when the hydrograph record used to determine these probabilities is not very long or where land use or climate is changing.

It is important to consider the intensity of extreme hydrodynamic forces as well as their frequency. Intensity is a measure of the strength, power or energy of a force. The intensity of a force will be a significant determinant of its possible impact on the proposed remedy. Tropical storms (including hurricanes) are often classified according to their intensity, that is, the effects at a particular place and time, which is a function of both the magnitude of and distance from the event. Tropical storms such as hurricanes are commonly classified by intensity using the Saffir-Simpson Scale of Category 1 to Category 5. Other physical forces and events, such as earthquakes, may be classified according to magnitude, that is, a measure of the strength of the force or the energy released by the event. Earthquakes are most commonly classified in this way (e.g., the Richter scale) although they may also be classified by intensity at a certain surface location (e.g., the Modified Mercalli scale).

For sites in areas that may be affected by extreme events, project managers should assess the record of occurrence near the site and determine the appropriate category or categories for analysis. The recurrence interval that is considered in a project generally relates to the magnitude of the resultant impacts. The choice of design event gives consideration to the impact of the event and the cost of designing against the event. For evaluation of contaminated sediment sites, project managers should evaluate the impacts on sediment and contaminant movement of a 100-year flood and other events or forces with a similar probability of occurrence (i.e., 0.01 in a year). A similar probability of occurrence may be appropriate for analysis of other extreme events such as hurricanes and earthquakes. At some sites, it may be appropriate to analyze the effects of events with lower and higher probabilities to understand the cost-effectiveness of various design decisions. Recorded characteristics of physical events, such as current velocities or wave heights, may provide project managers with parameters needed to calculate or model sediment movement. If information from historical records is insufficient or the historical record is too short to be useful, project managers should consider obtaining technical assistance to model a range of potential events to estimate effects on sediment movement and transport. Section 2.9 of this chapter discusses modeling in more detail.

2.8.3 Bioturbation

In some depositional environments, the most important natural process bringing contaminants to the sediment surface is bioturbation. Broadly speaking, bioturbation is the movement of sediment by the activities of aquatic organisms. Although this movement may be in many directions, it is the vertical mixing that is mainly of concern for project managers because it brings contaminants to the bed surface, where most exposures occur. While many discussions of bioturbation are focused on sediment dwelling animals, such as worms and clams, bioturbation may also include the activity of larger organisms such as fish and aquatic mammals. The effects of bioturbation can include the mixing of sediment layers, alteration of chemical forms of contaminants, bioaccumulation, and transport of contaminants from the sediment to interstitial/pore water or the water column. Many bottom-dwelling organisms physically move sediment particles during activities such as locomotion, feeding, and shelter building. These activities may alter sediment structure, biology, and chemistry, but the extent and magnitude of the alteration depends on site location, sediment type, and the types of organisms and contaminants present.

One factor of concern for understanding exposure is the depth to which significant physical mixing of sediment takes place, sometimes known as the "mixing zone." The depth of the mixing zone can be determined by examination of sediment cores (especially radioisotope analysis of core sections), or other site characterization data that displays the cumulative results of bioturbation through time, but useful information may also be gained from a sediment profile camera and other results. It is also useful to be aware of the typical burrowing depths of aquatic organisms in uncontaminated environments similar to the site. Project managers should keep in mind, however, that population density has a tremendous effect on whether organisms present at the site may have a significant effect on the mixing zone. It is important to understand the depth of the mixing zone in the various environments at a site because, where sediment is not subject to significant erosion and contaminants are not significantly mobilized by ground water advection, contaminants below this zone are unlikely to contribute to current or future risk at a site.

Typically, the population of benthic organisms is greatest in the top few centimeters of sediment. In fresh waters, the decline in population density with depth is such that the mixed layer is commonly five to 10 cm deep (NRC 2001), although it may be deeper, especially in marine waters with high populations of deep burrowing organisms. Highlight 2-11 provides examples of organisms that cause bioturbation, their activity type, and the general depth of the activity. However, project managers should also consider the activity type, the intensity of the activity, and organism population density, when determining the extent bioturbation should be considered in site evaluation. For example, the depth and effectiveness of bioturbation may be very different in a highly productive estuary and in a heavily used commercial boat slip.

A project manager should be aware of at least the following parameters when assessing the depth of the mixing zone and the potential role bioturbation will play on a given sediment bed:

- Site location - Salinity, water temperatures, depths, seasonal variation);

- Sediment type - Size distribution, organic and carbonate content, bulk density); and

- Organism type - Organisms either present and/or likely to recruit to and recolonize the area).

This analysis may be done for naturally deposited sediment as well as potential in-situ capping material or dredging backfill material. Where bioturbation is likely to be a significant process, it is important to evaluate the depth over which it causes significant mixing, using site-specific data and assistance by technical experts, to assess alternative approaches for the site.

Highlight 2-11: Sample Depths of Bioturbation Activity

Organism	Activity Type	Depth	Reference
Freshwater			
Tubificid worm (oligochaete)	Burrowing/Feeding	0 - 3 cm	Matisoff, Wang, and McCall 1999 Pennak 1978
Midge and Mayfly (insects)	Burrowing/Feeding	0 - 15 cm	Matisoff and Wang 2000 Pennak 1978
Burbot (fish)	Burrowing	0 cm - 30 cm	Boyer et al. 1990
Marine/Estuarine (Atlantic Coast)			
Bristleworm (polychaete)	Burrowing	0 cm -15 cm	Hylleberg 1975
Bamboo worm (polychaete)	Burrowing/Feeding	0 cm - 20 cm	Rhoads 1967
Fiddler crab (crustacean)	Burrowing	0 cm - 30.5 cm	Warner 1977
Clam (bivalve)	Burrowing	0 cm - 3 cm	Risk and Moffat 1977
Marine/Estuarine (Pacific Coast)			
Bristleworm (polychaete)	Burrowing	0 cm - 15 cm	Hylleberg 1975
Fiddler crab (crustacean)	Burrowing	0 cm - 30.5 cm	Warner 1977
Clam (bivalve)	Burrowing	0 cm - 3 cm	Risk and Moffat 1977

2.8.4 Predicting the Consequences of Sediment and Contaminant Movement

Depending on its extent, movement of sediment or contaminants may or may not have significant consequences for risk, cost, or other important factors at a specific site. A number of differing factors may be important in determining whether expected or predicted movements are acceptable. Historical records or monitoring data for contaminant concentrations in sediment and water during events such as floods may be valuable in analyzing the increase in exposure and risk. Where this information is not available or has significant uncertainty, models may also be very useful to help understand and predict changes. This analysis should include increased risk from not only contaminant releases to the immediate water body, but wherever those contaminants are likely to be deposited. Increased cost may include remedy costs such as cap repair or costs related to contaminant dispersal, such as increased disposal cost of downstream navigational dredging. There may also be societal or cultural impacts of contaminant releases the project manager should consider, such as lost use of resources.

Project managers should assess the impacts of contaminant release on potential receptors on a site-specific basis, using information generated during the baseline human health and ecological risk assessments. Where natural recovery is being evaluated, project managers should recognize that not only the rate of net sedimentation, but also the frequency of erosive episodes, can help determine the rate of recovery for surface sediment and biota. Where in-situ capping is being evaluated, project managers should recognize that some amount of erosion and sediment transport may be acceptable and can be incorporated into plans for remedial design and cap maintenance. Increased risk to human or ecological receptors due to contaminant releases during dredging may be a related analysis when considering dredging. Comparing the increased risks, costs, or other consequences of sediment disruption due to natural causes or the remedy itself also may be an important part of the remedy selection process.

When evaluating remedy alternatives, the significance of potential harm due to reexposure of contaminated sediment or contaminated sediment redistribution is an important consideration. Factors to be considered include the nature of the contaminants, the nature of the potential receiving environment and biological receptors, and the potential for repair or recovery from the disturbance. These factors can be used to evaluate risks, costs, and/or other effects of different events on existing contaminated sediment or sediment remedies.

2.9 MODELING

Models are tools that are used at many sediment sites when characterizing site conditions, assessing risks, and/or evaluating remedial alternatives. A complex computer model (e.g., multi-dimensional numerical model) may not be needed if there is widespread agreement about the best remedial strategy based on an adequate understanding of site conditions, however, this is not often the case. At some sites, significant uncertainties exist about site characterization data and the processes that contribute to relative effectiveness of available remedial alternatives. Models can help fill gaps in knowledge and allow investigation of relationships and processes at a site that are not fully understood. For this reason, simple or complex modeling can play a role at most sediment sites.

There is a wide range of simpler empirical models and more robust computer models that can be applied to contaminated sediment sites. Simple models that aggregate processes or consider only some portion of a problem can provide significant insights and should be applied routinely at sediment sites, even complex sites. For example, simple steady-state mass balance models applied during a time period where there are no disruptive events can be used to determine whether external contaminant sources have been identified and properly quantified. Hydrodynamic model predictions of currents and associated bottom shear stresses can provide information about the potential for erosion and the degree of interaction between backwater and main channel areas. Even if a complex fate and transport model is never developed, simple modeling can be used to develop a better understanding of current and future site conditions and lead to selection of the most appropriate remedial alternative.

More complex fate and transport models are frequently applied to the most complex sites. These sites typically have a long history of data collection, have documented contaminant concentrations in sediment and biota, and often have fish consumption advisories already in place. Fate and transport models can be useful tools, even though they can be time consuming and expensive to apply at complex sediment sites. Most of these modeling efforts require large quantities of site-specific data, and typically a team of experienced modelers is needed. Nevertheless, these models are helpful in that they give, when properly applied, a more complete understanding of the transport and fate of contaminants than typically can be provided by empirical data (from field or laboratory) alone.

Whether and when to use a model, and what models to use, are site-specific decisions and modeling experts should be consulted. Modeling of contaminated sediment, just as with other modeling, should follow a systematic planning and implementation process. Technical assistance is available to project managers from EPA's Superfund Sediment Resource Center (SSRC), where experts from inside and outside the Agency may be accessed. Additional research about contaminated sediment transport and food web modeling is underway at the Office of Research and Development (ORD) (e.g., U.S. EPA in preparation 1 and 2). Project managers should monitor the Superfund sediment Web site at http://www.epa.gov/superfund/resources/sediment or contact their region's ORD Hazardous Substance Technical Liaison for more information.

In most cases, simple or complex models are expected to complement environmental measurements and address gaps that exist in empirical information. Examples of the uses of models include the following:

- Identifying data gaps during the initial phases of a site investigation;
- Illustrating how contaminant concentrations vary spatially at a site. Empirical information can provide useful benchmarks that can be interpolated or modeled to get a better understanding of the distribution of contaminants;
- Predicting contaminant fate and transport over long periods of time (e.g., decades) or during episodic, high-energy events (e.g., tropical storm or low-frequency flood event);
- Predicting future contaminant concentrations in sediment, water and biota to evaluate relative differences among the proposed remedial alternatives, ranging from monitored natural recovery to extensive removal; and
- Comparing modeled results to observed measurements to show convergence of information. Both modeling results and empirical data usually will have a measure of uncertainty, and modeling can help to examine the uncertainties (e.g., through sensitivity analysis) and refine estimates, which may include indications for where to sample next.

The use of models at sediment sites is not limited to the remedy selection phase. Most sites that use models for evaluation of proposed remedies have previously developed a mass balance or other type of model during the development of the baseline risk assessment. These models are often used to quantify the relationships among contaminant sources, exposure pathways, and receptors. At these sites, the same model is often used to predict the response of the system to various cleanup options. Where this is done, it is important to continue to test the model predictions by monitoring during the remedy implementation and post-remedy phases to assess whether cleanup is progressing as predicted by the model. Where it is not, information should be relayed to the modeling team so the model can be modified or recalibrated and then used to develop more accurate future predictions.

2.9.1 Sediment/Contaminant Transport and Fate Model Characteristics

A sediment/contaminant transport and fate model typically is a mathematical or conceptual representation of the movement of sediment and associated contaminants, and the chemical fate of those contaminants, as governed by physical, chemical and biological factors, in water bodies. Currently, there are two basic types of sediment transport models: conceptual and mathematical models. In addition, there are several different types of mathematical models. General types of models are described in Highlight 2-12, and an example of a conceptual site model is presented in Highlight 2-13.

Highlight 2-12: Key Characteristics of the Major Types of Sediment/Contaminant Transport and Fate Models

Conceptual Model:

Identifies the following: 1) contaminants of potential concern; 2) sources of the contaminants; 3) physical and biogeochemical processes and interactions that control the transport and fate of sediment and associated contaminants; 4) exposure pathways; and 5) ecological and human receptors.

Mathematical Model:

A set of equations that quantitatively represent the processes and interactions identified by the conceptual model that govern the transport and fate of sediment and associated contaminants. Mathematical models include analytical, regression, and numerical models.

Analytical Model:

An analytical model is one or more equations (e.g., simplified - a linearized, one-dimensional form of the advection-diffusion equation) for which a closed-form solution exists. This type of model may not be applicable at most sites due to the complexities associated with the forcing hydrodynamics and spatial and temporal heterogeneities in sediment and contaminant properties/characteristics.

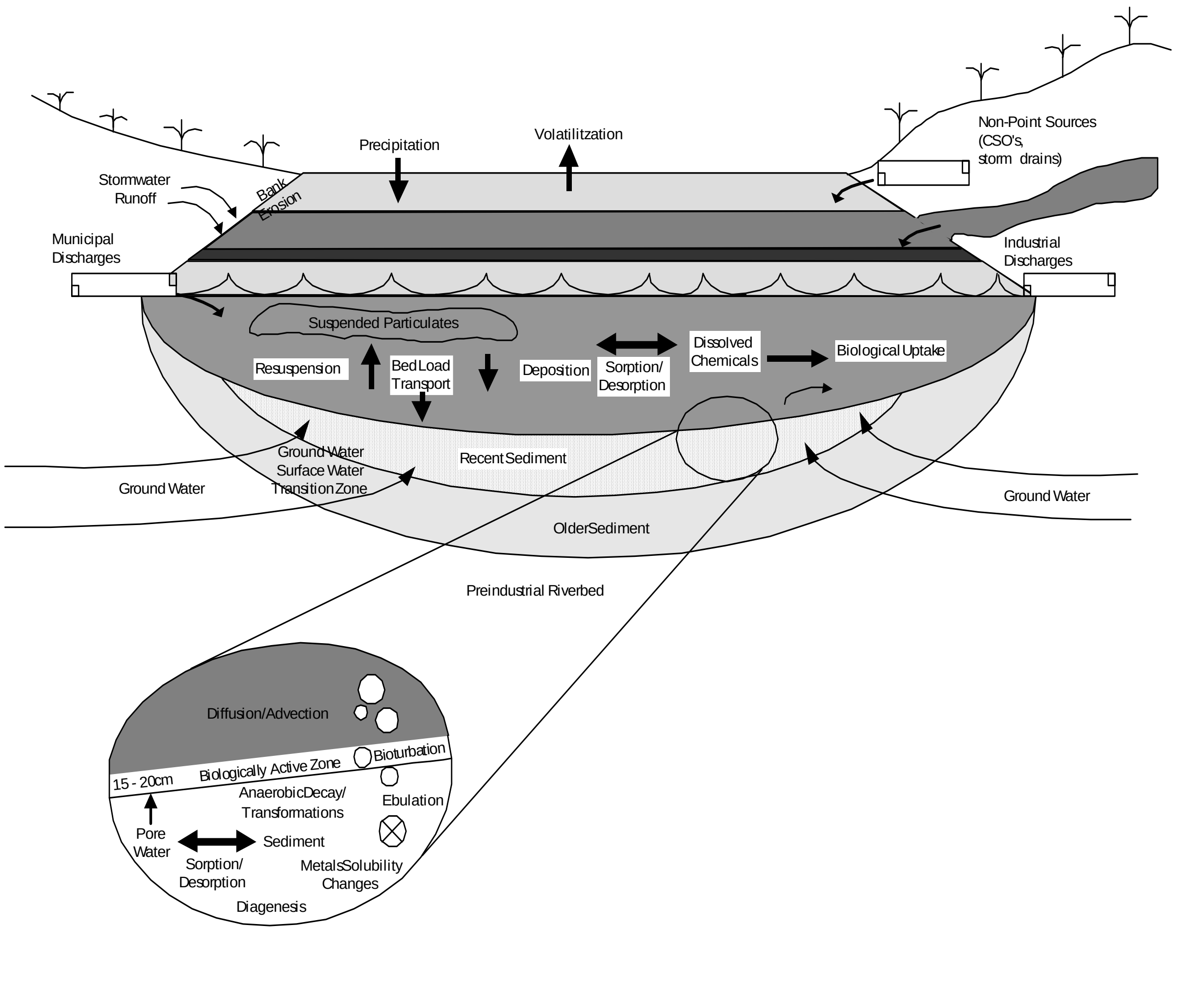
Regression Model:

A regression model is a statistically determined equation that relates a dependent variable to one or more independent variables. A stage-discharge rating curve is an example of a regression model in which stage (e.g., water level) and discharge (e.g., amount of water flow) are the independent and dependent variables, respectively.

Numerical Model:

In a numerical model, an approximate solution of the set of governing differential equations is obtained using a numerical technique. Examples of numerical techniques include finite difference and finite element methods. A numerical model is used when the processes being modeled are represented by nonlinear equations for which closed-form solutions do not exist.

Highlight 2-13: Sample Conceptual Site Model Focusing on Sediment-Water Interaction



Source: Modified from Sediment Management Workgroup (SMWG)

Typically, transport and fate models are inherently limited by our current understanding of the factors governing these processes and our ability to quantify them (i.e., represent mathematically their interactions and effects on the transport and fate of sediment and contaminants). Even the most complex sediment model may be a relatively simplistic representation of the movement of sediment through natural and engineered water bodies. It may be simplistic due to the following:

- Limitations in our understanding of natural systems, as reflected in the current state-of-the-science;
- Empiricism inherent in predicting flow-induced sediment transport, bank erosion, and nonpoint source loads;

- The relatively large space and time blocks used for modeling the water body; and

- The inability to realistically simulate geomorphological processes such as river meandering, bank erosion, and localized effects (e.g., due to natural debris or beaver dams).

Nevertheless, sediment/contaminant transport and fate models generally are useful tools when properly applied, although they are data intensive and require specialized expertise to apply and interpret the results.

2.9.2 Determining Whether A Mathematical Model is Appropriate

Since mathematical transport and fate models can be time-intensive and expensive to apply, their use and interpretation generally require specialized expertise. Because of this, mathematical modeling is not recommended for every sediment site. In some cases, existing empirical data and new monitoring data may be sufficient to support a decision. A mathematical modeling study is usually not warranted for very small (i.e., localized) sites, where cleanup may be relatively easy and inexpensive. Mathematical modeling generally is recommended for large or complex sites, especially where it is necessary to predict contaminant transport and fate over extended periods of time to evaluate relative differences among possible remedial approaches.

Project managers should use the following series of questions to help guide the process for determining the appropriate use of site-specific mathematical models:

- Have the questions or hypotheses the model is intended to answer been determined?

- Are historical data and/or simple quantitative techniques available to answer these questions with the desired accuracy?

- Have the spatial extent, heterogeneity, and levels of contamination at the site been defined?

- Have all significant ongoing sources of contamination been defined?

- Do sufficient data exist to support the use of a mathematical model, and if not, are time and resources available to collect the required data to achieve the desired level of confidence in model results? and

- Are time and resources available to perform the modeling study itself?

If the decision is made that some level of mathematical modeling is appropriate, the following section should assist project managers in deciding what type of model should be used.

2.9.3 Determining the Appropriate Level of Model

When the decision is made that a mathematical model is appropriate at a site, project managers should generally consider three steps in determining what level of modeling to use. It is important to consider all three steps in order. In some cases, these three steps may be more useful when performed in an iterative fashion (for example, based on additional data analysis or from results obtained during Step 3, it may become apparent that the conceptual site model (CSM) should be modified).

Step 1: Develop Conceptual Site Model

Development of a CSM is recommended as the key first step in this process in determining the level of modeling. As described in Section 2.2, a CSM identifies the processes and interactions that typically control the transport and fate of contaminants, including sediment associated contaminants. If this step is not performed, then the decision of what level of modeling is appropriate may be made with less than the requisite information that might be needed to make a scientifically defensible decision.

The development of a CSM usually requires examination of existing site data to assist in determining the significant physical and biogeochemical processes and interactions. Relatively simple quantitative expressions of key transport and fate processes using existing site data, such as presented by Reible and Thibodeaux (1999) or Cowen et al. (1999), may help in identifying those processes most significant at the site.

Step 2: Determine Processes that Can and Cannot be Currently Modeled

This step concerns determining if the most significant processes and interactions that control the transport and/or fate of sediment contaminants, as identified in the CSM, can be simulated with one or more existing sediment transport and fate models. Mathematical models (in particular numerical models) that have been developed can simulate most of the processes controlling the transport and fate of sediment and contaminants in water bodies (including a wide variety of physical, chemical, and biological processes). Highlight 2-14 depicts the inter-relationship of some major processes and the type of model with which they are associated. If it is determined that there are existing models capable of simulating at a minimum the most significant (i.e., first-order) processes and interactions, then the project manager should (using the appropriate technical experts) identify the types of models (e.g., analytical, regression, numerical) having this capability and eliminate from further consideration those types of models not having this capability.

Depending on the needs at the site, models or model components ("modules") may link many of these processes presented in Highlight 2-14 into one model. Examples of the processes that can be modeled include the following:

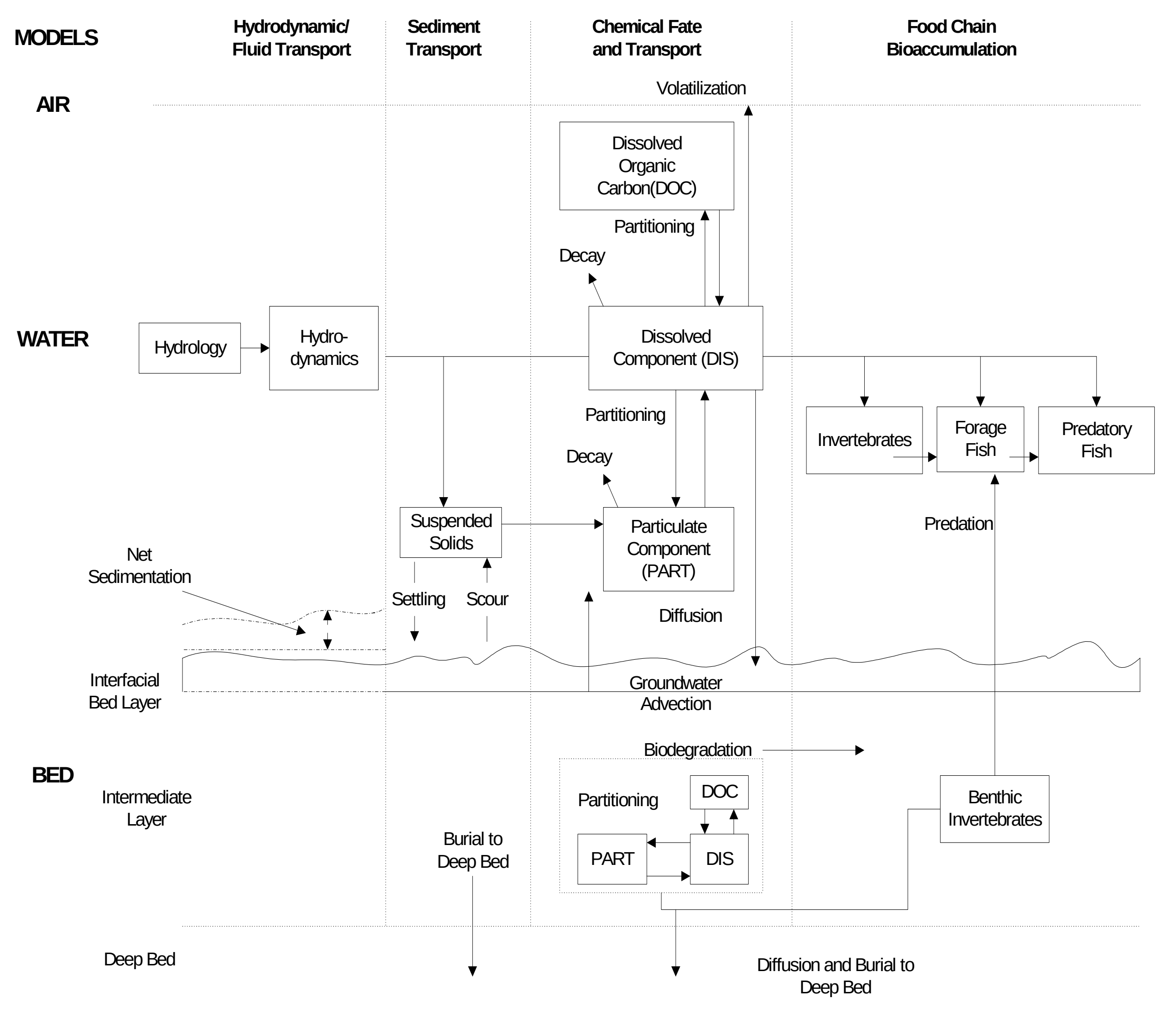
- *Land and air:* Physical processes that result in loading of contaminants to water bodies may include point discharges, overland flow (i.e., runoff), discharge of ground water, NAPL seeps, and air deposition;

- *Water column:* Physical processes that may result in movement of dissolved or sediment-sorbed contaminants include transport via the water's ambient flow (advection), diffusion, and settling of sediment particles containing sorbed contaminants;

- *Sediment bed:* Important physical processes include the movement of pore water and dissolved contaminants, seepage into and out of the sediment bed and banks, and the mixing of dissolved and sediment-sorbed contaminants by bioturbation. In addition, both sorbed and dissolved material may be exchanged between the water column and sediment bed due to sediment deposition and resuspension or erosion; and

- <u>*Water column and sediment bed:*</u> Physiochemical processes influencing the fate and transport of contaminants include two-phase and three-phase chemical partitioning as described below. Biogeochemical reaction processes influencing the fate of contaminants include speciation, volatilization, anaerobic gas formation, hydrolysis, oxidation, photolysis, biotransformation, and biological uptake.

Highlight 2-14: Sample Contaminant Exposure Modeling Framework



Source: NRC 2001

In Highlight 2-14 and in other modeling discussions, generally, “two-phase partitioning” refers to modeling the contaminant in two parts or phases: a bioavailable dissolved fraction and a generally non-bioavailable particulate fraction. In "three-phase partitioning," contaminant concentrations are normally considered in three phases: the bioavailable dissolved phase, a generally non-bioavailable dissolved organic carbon (DOC) phase, and a generally non-bioavailable particulate organic carbon phase.

If it is determined that there are no existing models capable of simulating, at a minimum, the most significant (i.e., first-order) processes and interactions, then project managers may need to rely on other tools or methods for evaluating proposed approaches, or develop and test new models or modules.

Examples of processes that cannot be dynamically simulated, even using state-of-the-art sediment transport models, may include geomorphological processes such as the development of meanders in streams and rivers, bank cutting/erosion, nepheloid layer sediment transport, and mud wave phenomena. However, there are empirical methods for simulating some of these processes, including estimating the total quantity of sediment introduced to a water body due to the failure of a river/stream bank. Likewise, there are empirical tools to estimate the importance of nepheloid layer transport (i.e., relatively high sediment flux occurring immediately above the sediment-water interface). Empirical tools are also being developed to simulate mud wave transport processes resulting from sediment disturbances such as dredging and resultant dispersal of contaminated sediment residuals.

<u>Step 3: Select an Appropriate Model</u>

If one or more models or types of mathematical models capable of simulating the controlling transport and fate processes and interactions exist, then project managers should use the process described above to choose the appropriate type of model (i.e., level of analysis). If the decision is made to apply a numerical model at a sediment site, selection of the most appropriate contaminated sediment transport and fate model to use at a specific site is one of the critical steps in a modeling program. During this process, familiarity with existing sediment transport models is essential. Comprehensive technical reviews of available models have been conducted by the EPA's ORD National Exposure Research Laboratory (see U.S. EPA in preparation 1 and 2).

2.9.4 Model Verification, Calibration, and Validation

Where numerical models are used, verification, calibration, and validation typically should be performed to yield a scientifically defensible modeling study. The project manager should be aware that the terms "verification" and "validation" are frequently used interchangeably in modeling literature. These terms, for purposes of this guidance, mean:

> <u>*Model verification*</u>: Evaluating the model theory, consistency of the computer code with model theory, and evaluation of the computer code for integrity in the calculations. This should be an ongoing process, especially for newer models. Model verification should be documented, or the model or model component should be peer-reviewed by an independent party if it is new.
>
> <u>*Model calibration*</u>: Using site-specific information from a historical period of time to adjust model parameters in the governing equations (e.g., bottom friction coefficient in hydrodynamic models) to obtain an optimal agreement between a measured data set and model calculations for the simulated state variables.
>
> <u>*Model validation*</u>: Demonstrating that the calibrated model accurately reproduces known conditions over a different period of time with the physical parameters and forcing functions

changed to reflect the conditions during the new simulation period, which is different from that used for calibration. The parameters adjusted during the calibration process should NOT be adjusted during validation. Model simulations during validation should be compared to the measured data set. If an acceptable level of agreement is achieved between the data and model simulations, then the model can be considered validated as an effective tool, at least for the range of conditions defined by the calibration and validation data sets. If an acceptable level of agreement is not achieved, then further analysis should be carried out to determine possible reasons for the differences between the model simulations and measured data during the validation period. The latter sometimes leads to refinement of the model (e.g., using a finer model grid) or to the addition of one or more physical/chemical processes that are represented in the model.

It is important that both calibration and validation be conducted at the space and time scales associated with the questions the model must answer. For example, if the model will be used to make decade-scale predictions, when possible, it should be compared to decade-scale trend data. Even when data exist for a much shorter time period than will be used for prediction, the long-term behavior of the model should be examined as a part of the calibration process. It is not unusual for a model to perform well for a short-term period, but produce unreasonable results when run for a much longer duration. The extent to which components of a modeling study are performed using verified models can determine to a large degree the defensibility of the modeling project. If a verified model has not been sufficiently calibrated or validated for a specific site, then the modeling study may lack defensibility and be of little value. Where possible, project managers should use verified models in the public domain, calibrated and validated to site-specific conditions. Proprietary models may also be useful, but project managers should be aware they contain code that has not been shared publicly and may not have been verified. The interpretation of modeling results and the reliance placed on those results should heavily consider the extent of documented model verification, calibration, and validation performed.

2.9.5 Sensitivity and Uncertainty of Models

Another important tool for understanding model results may be a sensitivity analysis. This process typically consists of varying each of the input parameters by a fixed percent (while holding the other parameters constant) to determine how the predictions vary. The resulting variations in the state variables are a measure of the sensitivity of the model predictions to the parameter whose value was varied. This can be very informative, especially in understanding how the various processes being modeled affect contaminant fate and transport and which are dominant. This analysis is frequently used to identify the model parameters having the most impact on model results, so that the project team can ensure these parameters are well constrained by site data.

Uncertainty in models usually results from the following three principal sources:

- The necessity for models to use equations that are simplifications and approximations of complex processes, which can result in uncertainty in just how well the equations represent the actual processes;

- The uncertain accuracy of the values used to parameterize the equations (i.e., uncertainty about how well the input data represent actual conditions); and

- The uncertain accuracy of model assumptions about future conditions, when using the model for prediction, (e.g., assumptions about future rainfall, land use, or upstream contaminant sources).

Typically, uncertainty analyses focus on only the second source, the accuracy of the input values for the model. While quantitative uncertainty analyses are possible and practical to perform with watershed loading models and food chain/web models, they are generally not so (at the current time) for fate and transport models. If a quantitative assessment of the uncertainty of fate and transport model predictions could be provided, the value of that prediction would be greatly increased. Lacking a quantitative uncertainty analysis, one method modeling teams might consider to assess uncertainty is to use bounding calculations to produce a conservative model outcome to compare to the model's best estimate outcome. This conservative model outcome may be developed by using parameter values that result in a conservative outcome but do not result in significantly degraded model performance, as measured by comparison to the calibration and validation data sets. A second method to assess uncertainty involves quantification of "model error" by comparison of results to the calibration and validation data and application of that error to model predictions, as described in Connolly and Tonelli (1985).

2.9.6 Peer Review

It is EPA policy that a peer review of numerical models is often appropriate to ensure that a model provides decision makers with useful and relevant information. Project managers should use EPA's *Guidance for Conducting External Peer Review of Environmental Regulatory Models* (U.S. EPA 1994c) and the *Peer Review Handbook* (U.S. EPA 2000e) to determine whether a peer review of a model is appropriate and, if so, what type of peer review should be used. As a rule of thumb, when a model is being used outside the niche for which it was developed, is being applied for the first time, or is a critical component of a decision that is very costly, a peer review should be performed. In addition, project managers should refer to OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediments at Hazardous Waste Sites*, Principle 6 (U.S. EPA 2002a; see Appendix A).

EPA peer review guidance for models (U.S. EPA 1994c) also notes that environmental models that may form part of the scientific basis for regulatory decision making at EPA are subject to the peer review policy. However, it cannot be more strongly stressed that peer review should be considered only for judging the scientific credibility of the model including applicability, uncertainty, and utility (including the potential for misuse) of results and not for directly advising the Agency on specific regulatory decisions stemming in part from consideration of model output. Peer reviewers advise the Agency regarding proper use and interpretation of a model; it is then the Agency's task to apply that advice properly to regulatory decisions.

Highlight 2-15 summarizes some important points to remember about modeling at sediment sites.

Highlight 2-15: Important Principles to Consider in Developing and Using Models at Sediment Sites

1. **Consider site complexity before deciding whether and how to apply a mathematical model.** Site complexity and controversy, available resources, project schedule, and the level of uncertainty in model predictions that is acceptable, are generally the critical factors in determining the applicability and complexity of a mathematical model. Potential remedy cost and magnitude of risk are generally less important, but they can significantly affect the level of uncertainty that is acceptable.

2. **Develop and refine a conceptual site model that identifies the key areas of uncertainty where modeling information may be needed.** When evaluating if a model is needed and in deciding which models might be appropriate, a conceptual site model should be developed that identifies the key exposure pathways, the key sediment and water-body characteristics, and the major sources of uncertainty that may affect the effectiveness of potential remedial alternatives (e.g., capping, dredging, and/or MNR).

3. **Determine what model output data are needed to facilitate decision making.** As part of problem formulation, the project manager should consider the following: 1) what site-specific information is needed to make the most appropriate remedy decision (e.g., degree of risk reduction that can be achieved, correlation between sediment cleanup levels and protective fish tissue levels, time to achieve risk reduction levels, degree of short-term risk); 2) what model(s) are capable of generating this information; and 3) how the model results can be used to help make these decisions. Site-specific data collection should concentrate on input parameters that will have the most influence on model outcome.

4. **Understand and explain model uncertainty.** The model assumptions, limitations, and the results of the sensitivity and uncertainty analyses should be clearly presented to decision makers and should be clearly explained in decision documents such as proposed plans and RODs.

5. **Conduct a complete modeling study.** If an intermediate or advanced level model is used in decision making, the following components should be included in every modeling effort:
    - Model verification (or peer-review if a new model is used)
    - Model calibration
    - Model validation

6. **Consider modeling results in conjunction with empirical data to inform site decision making.** Mathematical models are useful tools that, in conjunction with site environmental measurements, can be used to characterize current site conditions, predict future conditions and risks, and evaluate the effectiveness of remedial alternatives in reducing risk. Modeling results should generally not be relied upon exclusively as the basis for cleanup decisions.

7. **Learn from modeling efforts.** If post-remedy monitoring data demonstrate that the remedy is not performing as expected (e.g., fish tissue levels are much higher than predicted), consider sharing these data with the modeling team to allow them to perform a post-remedy validation of the model. This could provide a basis for model enhancements that would improve future model performance at other sites. If needed, this information could also be used to re-estimate the time frame when RAOs are expected to be met at the site.

Contaminated Sediment Remediation Guidance for Hazardous Waste Sites

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United States Environmental Protection Agency
Office of Solid Waste and Emergency Response

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ADDITIONAL COPIES

The *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* is available to download at no charge from EPA's Superfund program Web site at http://www.epa.gov/superfund/resources/sediment or from EPA's National Service Center for Environmental Publications (NSCEP), which maintains a searchable database of EPA publications at http://nepis.epa.gov. Hard copies of the document can be obtained by contacting NSCEP at (800) 490-1998 or ordered via the Internet at http://www.epa.gov/nscep. Fees for hard copy documents are determined by NSCEP.

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White Paper:
Important Considerations in the Derivation of Representative Background Concentrations for the Evaluation of Sediment Sites

Sediment Management Work Group (SMWG)

April 2018

Executive Summary

While there are some existing federal guidance documents that focus on deriving and applying background concentrations for contaminated upland sites, there is an absence of federal guidance related to deriving and applying background concentrations for contaminated sediment sites. This has resulted in significant variability, uncertainty, and disagreement regarding how representative background concentrations of chemicals of concern should be derived for sediment sites. This document discusses important considerations in the derivation of representative background concentrations of chemicals of concern to be used in the evaluation of sediment sites. Representative background concentrations are critical for putting risk into context, developing a cost-effective and technically feasible remedial approach, understanding the potential for recontamination, and ensuring long-term remedy success.

In order to identify common ground regarding appropriate technical approaches for deriving and applying background concentrations for contaminated sediment sites, a workshop was convened in November 2016. This workshop was hosted by the Sediment Management Work Group (SMWG), and included experts representing the U.S. Environmental Protection Agency (USEPA), other federal agencies, state government regulators, industry, private consulting firms, and academia. The goal of this workshop was to develop key considerations for deriving and applying representative background concentrations at contaminated sediment sites.

This document provides a compilation of technical considerations and methodologies that focuses on four key considerations in the process to derive representative background concentrations, as discussed at the workshop, as follows:

- A thorough understanding of a site is critical to the selection of the background reference areas from which representative background concentrations can be derived. A conceptual site model aids in understanding a site, and highlights important physical, chemical, and biological characteristics that should also be present at the background reference areas. This is discussed in more detail in **Section 2.0**.
- A primary objective of determining representative background concentrations should be to take into account existing levels of substances not contributed by the site, and to adequately account for chemical input that is expected to continue migrating onto the site during and after the completion of the remedy. Potential contributions to background chemical concentrations include non-site-related anthropogenic sources and contributions from watershed-based land use. These types of contributions are discussed in detail in **Sections 2.1 to 2.6**, as are sediment physical properties, hydrodynamic and sediment profile conditions, and geochemistry.
- Data collected to establish representative background concentrations and to compare these to site concentrations should be evaluated using a recognized statistical approach, by a statistician experienced in comparing site and background populations. The two most common statistical approaches used are point-by-point comparisons and background-site population comparisons. Outlier data points should not be removed as part of this statistical evaluation simply because they represent

the highest or lowest concentrations, unless there is a sound technical and statistical basis to do so, because doing so compromises the statistical approach underlying the analysis. Outlier data are often just a manifestation of random variability inherent to the environment. This is discussed in more detail in **Sections 3.0 to 3.5**.

- Geochemical evaluation of trace metals is an additional tool for deriving appropriate background concentrations for contaminated sediment sites. This technique is particularly useful and effective when it is not possible to identify background reference areas. It is typically used in conjunction with standard statistical evaluation. This is discussed in more detail in **Section 3.6**.

This document provides information to support the derivation of technically defensible representative background concentrations, including sites where background concentrations are greater than risk-based cleanup levels. The recommendations contained in this document are offered to help inform, improve, and increase the consistency of sediment site remedy decision-making. Such an approach is supported by existing federal guidance and by scientific and statistical principles underlying site remediation, as discussed in more detail in **Section 1.0** and **Section 4.0**.

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List of Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
APHA	American Public Health Association
BTV	Background threshold value
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	Conceptual site model
CSO	Combined sewer overflow
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
POC	Point of compliance
TOC	Total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

1.0 Introduction

The U.S. Environmental Protection Agency (USEPA) has recognized for more than 25 years that establishing a reliable representation of background is a critical issue at Superfund sites across the country (USEPA 1989a). This document has been prepared to detail the results of a workshop that was held to outline key considerations in the development of representative background concentrations (refer to Section 1.1) at sediment sites. Clear direction is needed because technically defensible, representative background concentrations are critical for putting risk into context; developing an appropriate, cost-effective, and technically feasible remedial approach; understanding the potential for recontamination; and ensuring long-term remedy success.

Once established, representative background concentrations may be applied as cleanup goals at sediment sites where these derived background concentrations are greater than risk-based cleanup levels. USEPA guidance appropriately notes: "The reasons for this approach include cost-effectiveness, technical practicability, and the potential for recontamination of remediated areas by surrounding areas with elevated background concentrations" (USEPA 2002). USEPA's approach, highlights the importance of deriving representative background concentrations that represent actual background. In some cases, derived representative background concentrations become *de facto* cleanup goals, thereby influencing the scope and scale of the remedy.

1.1 DEFINITIONS

The following USEPA-provided definitions are used in this document:

- **Background.** Substances or locations that are not influenced by the releases from a site and are usually described as naturally occurring or anthropogenic (USEPA 1989a, USEPA 2002).
    - **Natural background.** Naturally occurring substances present in the environment in forms that have not been influenced by human activity (USEPA 2002).
    - **Anthropogenic background.** Natural and human-made substances present in the environment as a result of human activities, not specifically related to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) release in question (USEPA 2002).
- **Background reference areas.** The areas where background samples for chemical concentrations are collected for comparison with samples collected on-site. The reference areas should have similar physical, chemical, geological, and biological characteristics as the site being investigated, but should not have been affected by activities on the site (USEPA 2002). Although in many cases the background reference areas are situated off-site, non-impacted on-site areas may also be suitable as background reference areas (USEPA 2002). Consistent with USEPA guidance, the background reference areas should include anthropogenic inputs unrelated to the site that are reflective of the larger region.

- **Reference area.** A reference area for ecological risk assessments is intended to "mirror the physical, climatic, chemical, and biological aspects of the Superfund Site" (USEPA 1994a). For clarity, this document discusses background reference areas exclusively. [1]
- **Conceptual site model.** A representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources to receptors. Essential elements of a CSM generally include information about contaminant sources, transport pathways, exposure pathways, and receptors. A good CSM can be a valuable tool in evaluating the potential effectiveness of remedial alternatives (USEPA 2005).
- **Outliers.** Measurements that are extremely large or small relative to the rest of the data and, therefore, are suspected of misrepresenting the population from which they were collected.
  - **False outliers.** Measurements that are very large or small relative to the rest of the data, but represent true extreme values of a distribution and indicate more variability in the population than was expected (USEPA 2006).
  - **True outliers.** Measurements that are very large or small relative to the rest of the data, but are a result of transcription errors, data-coding errors, or measurement system problems (USEPA 2006).

Additionally, the term representative background concentration(s) is used frequently throughout this document. **Representative background concentration**, for the purposes of this document, is defined as a chemical concentration that is inclusive of naturally occurring sources and anthropogenic sources not related to a CERCLA release. It is derived from sampling within representative background reference areas that may be located on-site and/or off-site, but are not affected by a site release or site activities. For man-made chemicals, the anthropogenic background concentration and the representative background concentrations are equivalent. For naturally occurring chemicals (e.g., metals), representative background concentrations are equivalent to the sum of the anthropogenic and natural background concentrations.

1.2 OBJECTIVES FOR DETERMINING REPRESENTATIVE BACKGROUND CONCENTRATIONS AND REMEDIATION DECISION-MAKING

At many sediment sites, multiple sources may contribute to the nature and extent of contamination. The largest contribution of contamination at Superfund sites is typically attributed to site releases. However, some contaminants can also result from natural and off-site sources.

[1] In background reference areas, sediment samples are taken for determination of chemical concentrations only. Of note, when ecological samples are taken from reference areas, sediment samples for measurements of chemical concentrations are usually taken at the same time. When chemical concentration data are available from reference areas and background reference areas, these data are usually pooled into a background dataset to calculate representative background concentrations.

The off-site contamination not associated with site releases is considered a component of representative background concentrations and will continue to be a source of contamination to the site, unless all transport pathways are controlled. A primary objective of determining representative background concentrations is to account for any background chemical input (both natural and anthropogenic) that is expected to continue migrating onto the site. It is recognized that one of the guiding principles for management of contaminated sediment sites is that sources should be controlled to the greatest extent feasible prior to initiating remediation at the subject site. According to USEPA, "Generally, significant continuing upland sources...should be controlled to the greatest extent possible before sediment cleanup" (USEPA 2005). However, it is rarely feasible to control all background sources.

When representative background concentrations accurately reflect ongoing chemical inputs to a site from all sources, this results in defensible representative background concentrations for use in the remedial investigation and remedy selection processes. In addition to informing or establishing cleanup levels, representative background concentrations can assist in:

- Determining a site boundary
- Determining chemicals of concern
- Establishing a realistic long-term monitoring plan, or optimizing existing long-term monitoring plans
- Assessing remedy success

In the absence of representative background concentrations for remediation decision-making, risk-based cleanup levels may be used inappropriately at sites where representative background concentrations are actually greater than risk-based concentrations. Alternatively, if the representative background concentration has been erroneously calculated (e.g., by the inappropriate exclusion of some outlier data points [false outliers]; refer to Section 1.1), inappropriately low cleanup goals could be used in the remedy selection process. Inevitably, in both cases, these sites will eventually return to background conditions after remediation has been completed, so the remedy would be considered a failure if it did not meet cleanup goals over the short- or long-term. This has been demonstrated on a number of sediment sites throughout the United States, under both federal and state lead (Nadeau *et al*. 2015). Moreover, attempting to cleanup to concentrations less than actual background is not sustainable over the long-term, can lead to unnecessary additional ecological disruption of sites, and can require considerable site remediation expenditures that serve no environmental or public health purpose. The considerations discussed in this document are intended to help promote a scientifically sound approach for establishing representative background concentrations, leading to decision-making that avoids costly perceived remedy failures due to recontamination.

1.3 CURRENT REGULATIONS AND GUIDANCE

At the federal level, background is discussed in a number of USEPA documents, but technical guidance describing protocols to derive representative background concentrations at sediment sites (as opposed to soil and groundwater at upland sites) has not been issued. This document has been formulated in the absence of existing USEPA-issued guidance on the derivation of representative background concentrations for contaminated sediment sites.

There are a number of relevant documents with information on the derivation of background concentrations for upland sites, including risk assessment and soil screening guidance (USEPA 1989a, USEPA 1989b, USEPA 1991, USEPA 1994a, USEPA 1994b, USEPA 1996, USEPA 1997, USEPA 2001, USEPA 2003, USEPA 2009), determination of background concentrations of inorganics in soils and sediments at a hazardous waste site (Breckenridge and Crockett 1995), and guidance concerning the characterization of background chemicals in soil at Superfund sites (USEPA 2001).

Further, USEPA issued a guidance document in 2002 entitled, "Role of Background in the CERCLA Cleanup Program"; this document seeks to clarify the "preferred approach for the consideration of background constituent concentrations of hazardous pollutants, and contaminants in certain steps of the remedy selection process, such as risk assessment and risk management" (USEPA 2002). That document is intended to serve as national policy and is the most current federal guidance on deriving and applying background at upland sites; it also finalizes the discussion of sampling and statistical analysis of representative background concentrations at soil sites. The 2002 USEPA guidance does not address sediment sites[2], but considerations for sediment site characterization, as well as developing appropriate cleanup goals, are discussed in USEPA guidance from 2005 concerning remediation of contaminated sediment sites (USEPA 2005). However, the 2005 guidance does not provide a detailed discussion describing the derivation of representative background concentrations.

In addition to the federal guidance, some states have also issued guidance related to the derivation of representative background and/or the use of background; this document focuses on representative background as it applies to federally regulated sites. State guidance is typically similar to federal guidance, but may use different terminology, or may vary in other ways, such as specific statistical procedures recommended for the screening of background data, characterization of background distributions, and calculation of background threshold values (BTV).

Finally, in order to determine representative background concentrations, it is typically necessary to identify background reference areas. A separate, but related, concept that is not addressed here is the use of reference areas in the evaluation of potential ecological risk. This involves identifying one or more suitable reference areas to facilitate sampling for the comparison of toxicological responses and, frequently, resident biological communities (e.g., benthic macroinvertebrates). Note that there are additional documents relevant to the ecological risk evaluation process (for example, USEPA 1997 and 1999a), and again, the terminology may be slightly different.

[2] The document indicates that "guidance may be updated in the future to address non-soil media. Non-soil media are dynamic and influenced by upstream or upgradient sources. Such media—air, groundwater, surface water, and sediments—typically require additional analyses of release and transport, involve more complex spatial and temporal sampling strategies, and require different ways of combining and analyzing data."

2.0 Elements of a Conceptual Site Model

Representative background concentrations are typically derived from data collected from background reference areas. Selection of appropriate background reference areas depends on a thorough understanding of the site. As provided in the definition in Section 1.1, background reference areas should have key similarities to the site, reflecting similar physical, chemical, geological, and biological conditions; and importantly, should not be influenced by site releases. In addition, background reference areas should have similar land use to the subject site (e.g., if the subject site is in an industrial area, the background reference areas should not be located in watersheds characterized by residential or rural land uses). Ultimately, background reference areas selected for derivation of representative background concentrations should be as similar to the site as possible, while recognizing there will always be differences between the two.

A CSM is typically developed with the objective of obtaining and presenting a detailed understanding of a site. A CSM is "a representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources to receptors" (USEPA 2005). The CSM should provide a robust understanding of the physical characteristics of the site, as well as the sources of contamination, potentially contaminated media, chemical transport pathways, and exposure pathways applicable for ecological and human receptors.[3] While the CSM is an important tool for selecting background reference areas, it also provides additional clarity and steering for proponents, consultants, and the community, and can highlight options for risk reduction.

Figure 1 presents a simplified CSM for a sediment site, focusing on the anthropogenic inputs and natural characteristics outlined in this section. Importantly, Figure 1 does not depict complex interactions, such as the cycling of chemicals of concern within the environmental system, which can be important at some sites. Additionally, Figure 1 and Section 2.0 are not inclusive of all possible chemical fate/transport and exposure pathways that may be relevant to the derivation of representative background concentrations at different sites (e.g., groundwater-surface water interactions, spills).

[3] The typical elements of a CSM for sediment are provided in more detail in USEPA's "Contaminated Sediment Remediation Guidance for Hazardous Waste Sites," (USEPA 2005), which also includes a discussion of CSMs and their value or applicability at sediment sites.

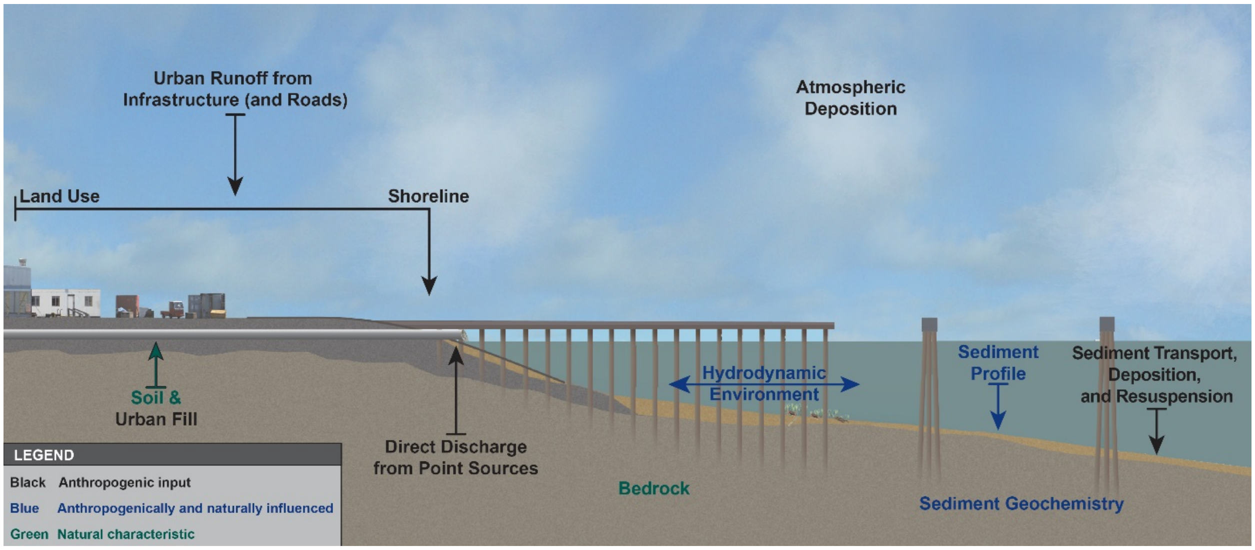

Figure 1. Key Considerations in Conceptual Site Model Development

Ultimately, background reference areas selected for derivation of representative background concentrations should be as similar to the site as possible, except for site-related releases. Therefore, developing a robust CSM will help to ensure that the selected background reference areas are similar to the site and will inherently provide an increased understanding of the factors that may contribute to representative background concentrations at the site. Factors that typically contribute to representative background concentrations (and chemical concentrations on a site, as would likely be shown through the CSM) are detailed in this section, and these factors should be considered when developing the study design for representative background determination.

Sections 2.1 through 2.6 discuss some of the key complexities that are encountered during the CSM development process at sediment sites, and the discussion has been developed for use by a broad audience. Some of the more specific technical considerations, such as evaluation of total organic content and grain size and their specific relationship to organic compounds and data treatment, are not discussed specifically within the following sections. However, the overarching principle is that a robust CSM assists in selection of representative background areas, and these background areas need to reflect the site as closely as possible, with the exception of site-related inputs.

2.1 LAND USE WITHIN A WATERSHED

Several studies, detailed in these subsections, have demonstrated that the degree of urbanization, intensity of land use, and land cover patterns adjacent to a site (or background reference areas) are correlated with chemical concentrations. Generally, a practitioner should recognize that contaminant concentrations tend to increase as the degree of urbanization increases (Moran *et al.* 2012). The degree of urbanization positively correlates to the level of chemical input that can be expected to migrate onto the site before, during, and after the completion of the remedy; so this should be considered in selecting background reference areas and determining representative background concentrations.

2.1.1 Degree of Urbanization

Contamination associated with urbanization moves through the environment via a variety of transport pathways, including surface water transport, urban runoff, bank erosion, and sediment resuspension, among others.

The USGS has evaluated chemical concentrations in watersheds across different degrees of urbanization, in order to better understand the correlation between urban land use and chemical concentrations. These studies have shown that environmental media in more urbanized areas contain elevated concentrations of chemicals compared to less urban areas (Nowell *et al*. 2013, Kemble *et al*. 2013). These studies concluded that concentrations of a wide range of contaminants, including polycyclic aromatic hydrocarbons (PAHs), PCBs, organochlorine pesticides, and metals, were “significantly related to urbanization across the study areas” (Nowell *et al*. 2013).

Consequently, historical and current land use within a watershed has a direct and potentially major influence on anthropogenic background conditions (chemical concentrations). The type and intensity of land use surrounding selected background reference areas should be as similar as possible to that observed at the site, to account for chemical input that is associated with urbanization. This practice will ensure that anthropogenic background concentrations reflect the level of contamination that is generally associated with land use in the vicinity of the site, absent contributions from the site itself. This practice will help facilitate the derivation of representative background concentrations for determining achievable cleanup goals.

2.1.2 Shoreline Conditions

Shoreline condition should be evaluated as part of CSM development (USEPA 2005) when screening and selecting background reference areas. Waterfront development, particularly for industrial purposes, typically includes hardened shorelines such as sheetpile walls, bulkheads, or riprap slopes. Hardened shorelines protect against erosion, but may be susceptible to sediment contaminant migration through sheetpile seams and holes in older steel, due to corrosion or accidental puncture. Unprotected shorelines are more susceptible to erosion from upland runoff, tidal action, and storm surge, releasing soils that may be impacted by site-related activities to the water body.

A number of examples of recontamination in Superfund sites due to contaminated soil erosion (e.g., slumping under docks and scouring after high flow storm events) are described by the Association of State and Territorial Solid Waste Management Officials in *Sediment Remedy Effectiveness and Recontamination: Selected Case Studies* (ASTSWMO 2013). Case studies described include the Torch Lake/Quincy Smelter Site in Michigan and the Denny Way Combined Sewer Overflow (CSO) Site in Washington, where continuing shoreline erosion has negatively impacted the remedies.

Alternatively, natural shorelines may indicate lower levels of land use intensity and could result in a source of less impacted eroding material entering the water column. Potential migration of impacted bank soil into adjacent sediments should be considered, because this migration could impact chemical concentrations in adjacent sediments and downstream.

Finally, floodplains and marshes within sites (or near the site), especially when tidally influenced, are particularly challenging. These features can cover a large surface area, usually have complex patterns of erosion and deposition, and the location of the shoreline is constantly changing. As such, inputs from these areas are often critical components in developing a robust CSM for the site.

2.2 WATERSHED INPUTS

Sediment sites are predominantly affected by historical chemical contributions and point-source releases. These sites are often located within urban areas, with multiple potential sources of additional and on-going chemical inputs from point and non-point sources that are unrelated to the site. Sources of contamination that are not site-related, but are from within the watershed, both historical and current, may include many of the same chemicals being studied at the subject sediment site, making it difficult to discern between site-related releases and inputs from background sources.

For example, almost half of the largest sediment sites have PCBs as a major contaminant, and approximately a quarter or more are contaminated with metals and PAHs from legacy or point-source releases (USEPA 2005). These contaminants are also ubiquitous in the urban environment and are transported through urban runoff, atmospheric deposition, and direct discharges from outfalls (municipal and/or industrial). Consequently, it is critical to recognize that these ongoing sources will continue to contribute contaminant concentrations to background reference areas and the site. Thus, these sources should be included in determining representative background concentrations for these background reference areas.

2.2.1 Urban Runoff

Urban runoff is non-point source pollution defined as “stormwater from city streets and adjacent domestic or commercial properties that carries pollutants of various kinds into the sewer systems and receiving waters” (USEPA 2010). Urban runoff is considered to be a significant contributor of contamination to watersheds and sediments, and contains many chemicals most commonly found at sediment sites (PCBs, PAHs, and metals), as noted in Section 2.2 (USEPA 1995a).

Urban runoff also contains chemicals that are commonly found in urban infrastructure, including asphalt roads, pavement sealants, building materials, roofing materials, and galvanized fences. For example, a recent study by the USGS and the Milwaukee Metropolitan Sewage District stated that “coal-tar pavement sealant was indicated as the primary source of PAHs in a majority of streambed sediment samples, contributing an estimated 77 percent of total PAHs to samples, on average” (Baldwin *et al*. 2016). Releases to the environment are also attributable to motor vehicle use; wear on automotive parts (e.g., tires, brake pads), and vehicle emissions (Chalmers *et al*. 2007, Gallagher *et al*. 2014, Turner and Hallett 2012). Other sources of different chemicals, such as home pesticide application and improper waste disposal, also contribute to chemical concentrations in urban runoff.

Therefore, contributions and chemical loading from urban runoff to a site should also be included in the development of representative background concentrations. Chemical inputs from urban runoff to a site and background reference areas should be as similar as possible in order to obtain representative background concentrations for use at the site.

2.2.2 Direct Discharges

In general, direct discharges are associated with industrial facilities, or municipally owned systems that discharge wastewater and/or stormwater to water bodies through permitted (or unpermitted) conveyance systems, via discharge points such as outfalls and CSOs. Chemical loading from wastewater and/or stormwater discharge is managed by the National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act, which may set limits for chemical concentrations for discharges from these conveyance systems, but does not completely eliminate chemical loading from the discharge. Additionally, the regulatory programs may not measure or exercise authority over chemicals associated with sediment sites, such as PCBs.

In 2006, a Phthalates Work Group (Work Group) was formed by the USEPA and state and local agencies to address recontamination from phthalates observed in the Thea Foss Waterway located within the Commencement Bay Superfund Site in Tacoma, Washington. A key conclusion identified by the Work Group is that “rapid accumulation of phthalates in sediments (after cleanup) is associated with urban stormwater outfalls” (Work Group 2007). In particular, the head of the Thea Foss Waterway has two 96-inch-diameter stormwater pipes that continuously discharge untreated and treated industrial stormwater, in addition to untreated residential stormwater. These outfalls were determined to be a main source of phthalate input, and the resulting recontamination to the Thea Foss Waterway, particularly in the vicinity of the outfalls (ASTSWMO 2013).

Chemical loading to a site from direct discharges should be accounted for in representative background concentrations. “In some cases, as part of a response to address CERCLA releases of hazardous substances, pollutants, and contaminants, USEPA may also address some of the background contamination that is present on a site due to area-wide contamination” (USEPA 2002). As much as practical, direct discharges affecting background reference areas should be as closely matched as possible to the direct discharges affecting a site. Municipalities overseeing wastewater treatment plant and CSO discharges within a waterbody undergoing sediment cleanup may have data on chemical concentrations in the treatment plant and CSO discharges, which can also be useful in the derivation of representative background concentrations.

2.2.3 Sediment Transport

Sediment sites are dynamic in nature, as they are consistently receiving suspended sediments from off-site areas. Those off-site areas contain background concentrations of contaminants from anthropogenic sources, and may also contain concentrations of naturally occurring chemicals similar to the chemicals of concern for the site. At the Lower Duwamish Waterway Superfund site, sediment transport modeling performed as part of the Remedial Investigation/Feasibility Study indicated that “approximately 99 percent of the total external sediment particle load to the Lower Duwamish Waterway comes from the Green River, upstream of the Lower Duwamish Waterway” (Windward 2010).

An analysis of suspended sediments collected upstream of the Lower Duwamish Waterway site performed by the Washington State Department of Ecology indicated that this loading could potentially be a post-remedy source of recontamination to sediments (Ecology 2009), because the upstream sediment contains chemicals (such as PCBs) that are found at high concentrations throughout the downstream site. A dredge and backfill early action remedy was conducted along the Lower Duwamish Waterway between 2013 and 2015. Within months of completing the remedy, high levels of PCBs were measured in material deposited on the clean sediment surface, with concentrations much greater than what was predicted to occur. Similar post-remedial recontamination was also observed at locations where other early actions were performed on the Duwamish (AMEC Foster Wheeler 2017).

Background reference areas in non-tidal riverine systems are frequently located immediately upstream of the site. In tidally influenced sites, the situation is considerably more complex. At tidally influenced sites, sediment transport into the site may result from upstream sources and may also involve contributions from receiving bodies downstream of the site as sediments are transported on incoming tides. Therefore, within tidal systems it is extremely important to have a strong understanding of hydrodynamics and sediment transport processes. If downstream sediments contain equal or greater concentrations of contaminants than are found at the site, these downstream sediments can be a continuing source of contaminant input to the site and should be considered in developing representative background concentrations.

Because sediment resuspension is a transport pathway for contamination, it is important to acknowledge that representative background levels of contamination will inevitably move into a site through this natural process. It is also important to understand the diversity of depositional environments and the many varying factors such as current directions, tidal pumping, and constant or episodic sediment transport processes. Consideration should be given to multiple potentially significant factors influencing sediment transport at coastal/tidal sites, including the effects of flood events and storm surges. Among these, downstream flows intersect with the tide to create a salt wedge and an estuarine turbidity maximum where dissolved materials flocculate and deposit. This effect, combined with suspended particulate material, creates a locally elevated area of turbidity that moves through the estuary and contributes to sediment transport and deposition. Finally, in some riverine or estuarine systems, the current can reverse direction and head upriver, under certain circumstances.

2.2.4 Atmospheric Deposition

Atmospheric deposition from industrial and urban areas, and areas near major transportation corridors, is a recognized pathway of contamination, particularly for those contaminants ubiquitously found in the environment; these include metals, PAHs, PCBs, and pesticides, as discussed in Section 2.2 (Larson *et al*. 1997, ESA 2000, Landis and Keeler, 2002, Rolfhus *et al*. 2003, Kuang *et al*. 2003, USGS 2005, Urbaniak 2007, Brandenberger *et al*. 2010, Zhang *et al*. 2013, Amodio *et al*. 2014). The impact of atmospheric deposition can be challenging to ascertain. Types and volumes of pollutants deposited from the atmosphere will vary depending on atmospheric conditions (e.g., wind speed, temperature, and rainfall) and particle characteristics (size and shape). The influence of these factors on the resulting contaminant deposition rate may vary (Amodio *et al*. 2014).

Winds can carry chemicals through the air from great distances, further confounding the identification and control of non-point sources of contamination (Cohen *et al*. 1997). At sites with relatively uniform sources of atmospheric deposition (e.g., transportation corridors and urbanized, non-industrial areas), typical concentrations and mass loading effects are usually established through a literature review. Additionally, sites in industrial areas with contributions of airborne chemicals may warrant further consideration of site-specific variations (e.g., physical and chemical characteristics of specific industrial emissions, localized wind patterns) that influence deposition patterns, which may not be readily apparent during a literature review.

In Washington State, studies of air deposition and resulting mass flux loading have generally concluded that air deposition is a small but potentially significant source of certain persistent chemicals, and may account for up to 5 percent of the measured concentration of any particular chemical in sediment that is well outside of the influence of urbanized areas (Brandenberger *et al.* 2010). Similar studies of atmospheric deposition in the Great Lakes region have concluded that atmospheric deposition is a significant source of mercury and some other trace metals to Lake Michigan and Lake Superior (Landis and Keeler 2002, Rolfhus *et al.* 2003). Studies of zinc loading to the Santa Monica Bay determined that atmospheric deposition was responsible for 62 percent of the measured zinc concentration in sediments (ESA 2000). The Delaware River Basin Commission found that "air concentrations of PCBs in the region currently are two orders of magnitude above the concentration required to achieve equilibrium and halt contributions of PCBs from the air to the water" (Fikslin and Suk 2003). Substantial additional literature is available documenting the contributions of air deposition to elevated chemical concentrations in surface sediment. The contribution of chemicals from this pathway should be recognized both at a site, and at its background reference areas; in fact, background reference areas should reflect atmospheric deposition conditions observed at the site.

2.3 SOURCE CONTROL

Source control is generally defined as efforts to eliminate or reduce, to the extent practicable, the release of chemicals from point and non-point sources to a water body (USEPA 2005). Source control measures vary, depending on the transport pathway. For example, reducing contamination from urban runoff typically requires different measures than those used to reduce contamination from direct discharges, although the efforts may be coordinated.

Source control should be fully complete, or at least substantially completed, before remediation of a sediment site begins. If source control has not been completed or is not feasible, then it is critical that the potential inputs from uncontrolled ongoing sources be included in the determination of representative background concentrations, because these inputs would continue to affect the site after remediation and that recontamination of the completed remedy would occur. For example, at a riverine site there may be substantial ongoing CSO contributions upstream of the site boundary, or from within the site itself. If the municipality responsible for the CSOs is not able to implement source control prior to site remediation, the CSO input must be included and represented in the derivation of representative background concentrations, as the input from these point sources will continue into the future, after completion of the remedy.

In general, it is important to recognize that, while source control is key, in many sites it may be impossible to eliminate source contributions altogether. This is particularly the case at urbanized and/or tidally influenced sites. The inability to eliminate ongoing source contributions makes it all the more critical to take ongoing sources into account when setting representative background concentrations for the site.

2.4 SEDIMENT PHYSICAL PROPERTIES

The physical properties of sediment strongly influence the distribution of naturally occurring and anthropogenic background chemicals in the environment. Sediment consists of organic material, inorganic material, and pore water. The relative abundance of these components varies vertically and horizontally within a sediment body, resulting in variable distribution of chemicals at a sediment site. Metals concentrations, in particular, can be heavily influenced by natural processes. Since representative background includes natural sources (as well as anthropogenic sources), a discussion related to contributions of natural background is included within this document.

The organic fraction has an important effect on the concentration of chemicals, because of its high capacity for sorption of some contaminants. The water fraction fills pore space within the sediment, allows for the transport of dissolved chemicals, and is subject to geochemical conditions that strongly influence the transport and sorption of metals (refer to Section 2.6). The inorganic fraction typically makes up the largest portion of sediment mass; the relative fractions of sand, silt, and clay determine the sediment texture.

To accurately quantify sediment characteristics, geotechnical testing and general chemistry analyses are generally recommended, these should be conducted according to ASTM International geotechnical testing standards and USEPA analytical methods. The sediment type (ASTM 2009), particle size (ASTM 2017a, 2017b), density (ASTM 2017c), and moisture content (ASTM 2010) should be the focus of geotechnical tests. The general chemistry analyses that are recommended include sediment pH (USEPA 2000), oxidation-reduction conditions (redox potential; APHA 2011), and total organic carbon (TOC) content (USEPA 1999b).

Sediment texture has a substantial effect on the distribution of chemicals of concern in sediment. Several grain size classifications are available for soil classification, and the Unified Soil Classification System (USCS; ASTM 2011) is most commonly used to classify sediments. Fine-grained sediments, particularly those with a high percentage of clay-sized particles and organic content (as measured by TOC) have greater surface area, so they typically have greater sorption capacity for some contaminants than medium and coarse-grained sediments. Silts typically have moderate sorption capacity, while sands and gravels have lower sorption capacity.

In addition to sediment texture, sorption capacity of some fine-grained sediment is enhanced by surface charge. For example, clays and organic colloids tend to be highly charged relative to their surface areas. Clay minerals are typically negatively charged under normal pH conditions, so they attract positively charged trace metals ions for sorption. This results in clay-rich, fine-grained sediments that have greater trace and reference metal concentrations (refer to Section 2.6). In addition, metal concentrations (in particular) tend to be inversely proportional to grain size.

Given the ability of sediment physical properties to influence the distribution of chemicals in the environment, this is an important consideration in developing a CSM to support representative background determination.

2.5 HYDRODYNAMIC ENVIRONMENT AND SEDIMENT PROFILE

Sediment characteristics that strongly influence the distribution of both naturally occurring and anthropogenic background chemicals are determined chiefly by the physical configuration and hydrodynamic characteristics of the depositional environment. In general, coarse-grained sediments such as sands are deposited in relatively high-energy environments (such as beaches and river channels), while fine sediments settle out only when they reach lower energy areas (such as offshore, lakes, and more quiescent areas of rivers and streams). As described in Section 2.4, fine sediments typically have a greater sorption capacity for contaminants than coarse-grained sediments, so representative background concentrations tend to be greater in more quiescent sediment environments, where the percentage of fine sediments is greater.

The vertical profile of sediment may vary significantly in composition, texture, chemical, and biological characteristics. Changes in the hydrodynamic environment and sediment sources can result in distinct layering. Change in land use over time, such as increasing urbanization, may produce layers with different compositions, texture, and concentrations of anthropogenic background chemicals. Natural or artificial changes to vegetation within a watershed may alter the concentration of organic carbon in sediment layers. All of these factors can influence the distribution of chemicals at a site and within its background reference areas.

The rates of sediment deposition, erosion and removal, and mixing vary widely among aquatic environments and should also be assessed as part of the CSM, as these factors affect chemical distribution in sediments. Pore space and volume of the water within sediments is decreased by compaction as sediments are buried. During this process, chemicals present in sediments may be vertically redistributed by mixing of surface and deeper sediments. Sediment mixing may also occur through bioturbation. Bioturbation may increase pore space, the volume of the water fraction, and organic content, and affect the partitioning of chemicals between aqueous and solid phases.

Age dating and chemical analysis of sediment core samples may indicate chemical concentrations that are associated with sediment layers deposited prior to site-related activities, which may be helpful in estimating representative background concentration ranges. The age of sediment layers and accumulation rates may be estimated by various methods, including radioisotopic decay measurements (USGS 1998).

2.6 GEOCHEMISTRY

It is important to identify the geochemical processes controlling element concentrations in sediment samples. Sediment geochemistry should be characterized by properly qualified geochemists in support of background analysis (e.g., to determine which samples to retain in the background dataset) and should be considered during subsequent comparisons of site versus background datasets. This is also important because metal concentrations (either naturally occurring, or from an anthropogenic source other than a release at a site) commonly exceed risk-based screening criteria. Geochemical processes relevant to background data evaluation include association of elements with minerals, sorption of elements on mineral surfaces, water chemistry, and water-mineral interactions. These topics are summarized in this section. Geochemical methods used for evaluating representative background metal concentrations in sediment are discussed further in Section 3.6.

Chemical properties of sediment particles and the surrounding aqueous phase strongly influence the distribution of metals, and for this reason are useful to measure and include in geochemical assessment of site data. Key properties include metal solubility, pH of the aqueous phase (including the overlying water column and pore water), redox potential of the aqueous phase, metal affinity for organic carbon, TOC concentrations, and reactions of metals with sulfide.

Metals concentrations are controlled by dissolution/precipitation reactions and adsorption/desorption (“sorption”) reactions. Highly soluble metals can remain mobile in the aqueous phase and can be dissolved from the sediment, while low solubility metals can precipitate and accumulate in sediments. The solubility of a metal is highly dependent on characteristics of the aqueous phase including pH, redox potential, and ionic strength. While elements differ in their response to changing pH, acidic conditions tend to dissolve and mobilize some metals, while basic pH conditions can precipitate other metals (resulting in greater concentrations in sediment). The pH also controls the net surface charge of particles, which is an important factor in determining sorption of metals on mineral surfaces. This is important due to the presence of clay minerals and metal oxides that have strong affinities to absorb specific trace metals.

Oxidizing conditions cause many metal ions (e.g., iron and manganese) to precipitate as oxides. Reducing conditions, such as in anoxic sediments, tend to keep specific elements in solution and mobile. In addition to naturally reducing conditions associated with peat or other organic materials in wetlands or similar environments, releases of organic contaminants can stimulate microbial activity, resulting in local reducing conditions and the mobilization of select metals.

Reducing conditions can cause the reductive dissolution of iron and manganese oxides, which may mobilize adsorbed trace elements. Reducing conditions may also directly reduce arsenic, selenium, antimony, molybdenum, and vanadium to more mobile valence states. Sulfate-reducing conditions in sediment can cause specific metals (e.g., arsenic, mercury, copper, lead, and zinc) to precipitate as (or with) insoluble sulfide phases. Sulfide ions, produced from the reduction of sulfate associated with the breakdown of organic compounds and as measured by acid-volatile sulfide, are usually associated with higher metals concentrations in sediment.

As noted previously, sediments with greater TOC concentrations typically have greater concentrations of specific trace elements (e.g., mercury, copper, tin, and uranium), because the organic particles have a greater sorptive capacity for these elements. However, greater TOC concentrations may be associated with reducing conditions, so the metals associated with the TOC may be less bioavailable.

The complexity of contaminant interactions, as overviewed in this section, may hinder the ability to identify the background reference areas with the same sediment geochemistry. For that reason, and the other reasons discussed throughout this document, it may be appropriate to identify and utilize multiple background reference areas in order to define a range of reference conditions.

3.0 Considerations in Data Review and Evaluation for the Determination of Background

Determination of background conditions at a sediment site almost always requires additional sampling and/or data analyses. To ensure the reliability of these evaluations, appropriate procedures should be considered during each phase of the investigation. Topics that require special attention include those related to the practical aspects of sampling design, selecting the representative background reference areas, using existing site data, choosing appropriate statistical methods for comparison, addressing perceived outliers, and geochemical analysis of sample data. These topics are discussed further in this section.

3.1 STUDY DESIGN CONSIDERATIONS

In general, unless existing contemporaneous data are adequate for extracting site-specific background data (USDON 2003; Singh *et al*. 2014), additional sampling focused on the determination of representative background concentrations is necessary. This process is often initiated by identifying suitable background reference areas. All samples collected within the background reference areas should be considered representative of background. Typical components of a sampling design, including the selected type of samples, sampling depth, and sampling methodology for the background reference areas, should match those used during site data collection. The number and location of background samples can be determined based on a number of different statistical approaches. One example is the United States Department of Energy's Visual Sample Plan (VSP Development Team 2017).

Agency agreement on the scope and scale of the sampling effort to determine representative background concentrations is important and should be captured in a site's Data Quality Objectives, using USEPA's Data Quality Assessment approach (USEPA 2006).

3.2 SELECTION OF REPRESENTATIVE BACKGROUND REFERENCE AREAS

One of the critical steps in a background analysis is the selection of representative background reference areas. As discussed in Sections 2.0 and 3.0, representative background reference areas are areas that have "the same physical, chemical, geological, and biological characteristics as the site being investigated, but [have] not been affected by activities at the site," and should be informed by the CSM (USEPA 2002). Further, "the ideal background reference area would have the same distribution of concentrations of the chemicals of concern as those which would be expected on the site if the site had never been impacted" (USEPA 2002). In addition, background reference areas need to include sources of contaminants that reflect the land use in the vicinity of the site, except for the inputs from releases or activities at the site. Unfortunately, selection of such an analogous area is complicated, due to the fact that sediment background often represents mixtures of naturally occurring and anthropogenic influences. In some cases, these mixtures yield geographically distinct background populations (e.g., background reference sub-areas with varying degrees of anthropogenic influences in different parts of the background reference areas). Under such situations, the part(s) of the targeted background reference areas (or sub-areas) that are most analogous to the site should be selected as the background reference areas. Selection of analogous background reference sub-areas is often supported by multiple lines of evidence, including degrees of urbanization, presence or absence of combined sewer outfalls, prevailing sediment TOC content, and grain sizes. Use of this selection methodology should result in a representative background dataset.

3.3 USE OF EXISTING SITE DATA

In many instances, site data include samples that are free of site influences. Particularly within a larger site dataset, there will be samples not affected by site releases that will be reflective of representative background conditions. In these cases, statistical methods, such as probability plot analyses, are recommended for extracting site-specific background datasets from existing site datasets (USDON 2003, Singh *et al*. 2014). This approach involves preparing iterative probability plots to determine break points, indicating a separation between the data points with site release impacts, and the data points free of site release influence that are suitable for use in deriving representative background concentrations. This procedure is especially useful for extracting representative background concentrations from large site datasets (Geiselbrecht *et al.* 2015).

The extraction of representative background concentrations from site data not only maximizes the utility of existing data, but also avoids the often complex task of selecting separate background reference areas that adequately represent the site. Even when data from separate off-site background reference areas are available, an extracted site-specific background dataset provides an additional line of evidence for determining representative background concentrations. Therefore, an analysis of existing site data is always recommended.

3.4 STATISTICAL COMPARISONS

Due to the different types of contamination (e.g., localized versus widespread), USEPA guidance recommends the use of simultaneous tests for a valid and complete comparison of background and site distributions (USEPA 2006). There are generally two statistical approaches for comparing site and background populations: (1) point-by-point comparisons, and (2) background-site population comparisons.

The point-by-point comparison approach is based on comparing individual site measurements to a given BTV, either to delineate the extent of impact or to identify localized (or "hot spot") contamination. A BTV is a specific value intended to define an upper limit to background concentrations for a given site. Common candidates for BTV include the upper tolerance limit (UTL; typically 95 percent confidence with 95 percent coverage), the upper prediction limit (UPL; typically 95 percent confidence), as well as the upper simultaneous limit (USL; typically 95 percent confidence; USEPA 2005). Regardless of the chosen BTV, point-by-point comparisons are prone to produce excessive false-positive errors. That is, as the number of comparisons increases, the chances of incorrectly detecting exceedances greater than BTV approaches 100 percent, even when the site data are derived from the background population (Gibbons 1994). In other words, the odds are very high (approaching 100 percent) that the analysis will report exceedances of background when the results do not truly exceed background. In fact, the Department of the Navy recommends against point-by-point comparisons, except when coupled with reverification sampling (USDON 2003).

The background-site population comparison approach, involving background reference areas versus site population comparisons, compares site population distribution to those of the background population distribution using specific statistical hypothesis tests. Some of these tests, such as the parametric t-test and the non-parametric Mann-Whitney U test are geared toward the comparison of central tendencies of two populations, to identify widespread contamination. Other tests focus on the comparison of the upper tails of the two populations to identify localized contaminations. In many instances, both widespread contamination and localized contamination should be tested concurrently. Selection of the appropriate test is contingent on the specific conditions presented in Figure 2. Typical conditions include the target statistics of interest, and the type of the distributions displayed by the investigated datasets, as well as their variance equivalency. These tests are designed to maintain the false negative error rates at the user-specified levels, often set at 1, 5, or 10 percent. In practice, non-parametric tests are often preferred because they do not require any specific distributional assumption about the investigated site and background data. Compared to point-by-point comparison, background-site population comparisons are less prone to excessive false-positive errors.

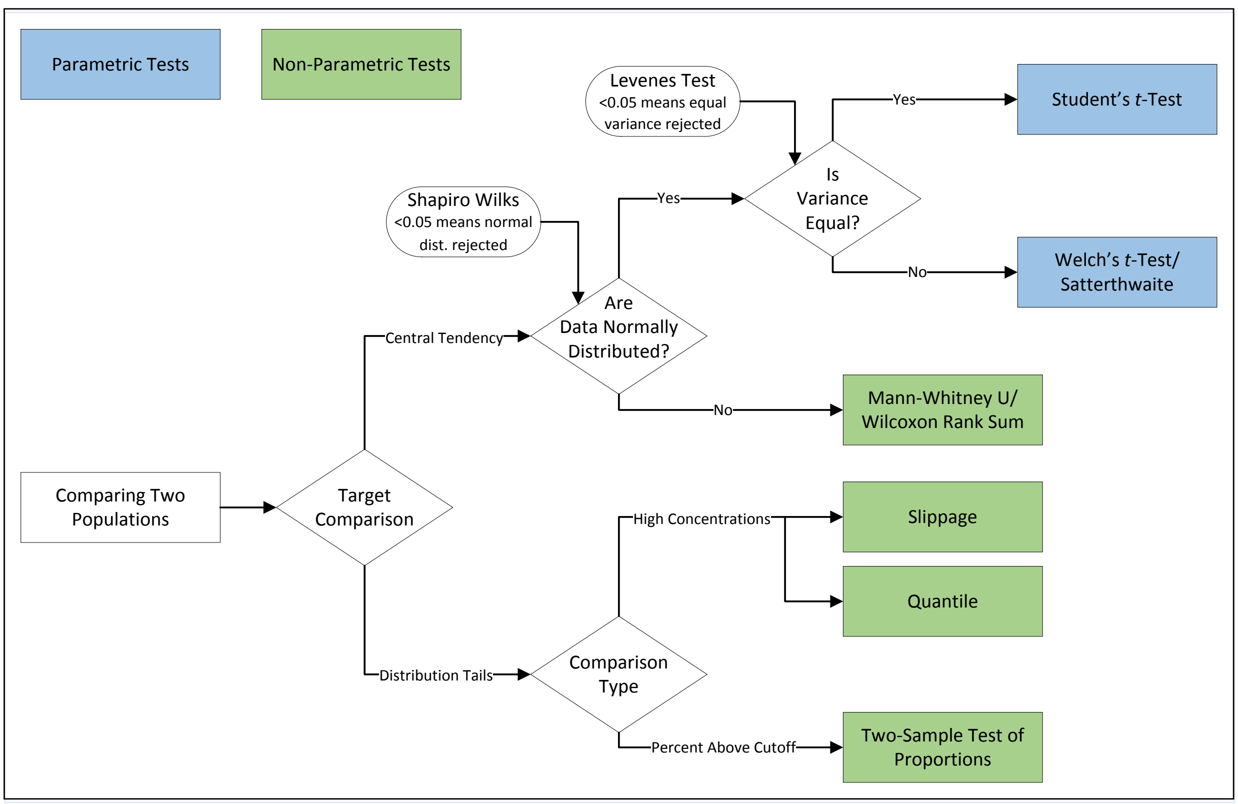

Figure 2. Statistical Tests for Comparison of Two Populations (adapted from USDON 2003)

3.5 OUTLIER EVALUATION

Some background measurements may be perceived as outliers, which are measurements that are disproportionately large or small relative to the rest of the data, so they are suspected of misrepresenting the population from which they were collected (USEPA 2006). Outliers can be attributed to two broad categories of causes: (1) outliers may represent very high or low values from the investigated population that have occurred by chance, or (2) outliers may be the results of errors such as faulty sample collection, laboratory equipment failure, and improper data entry (USEPA 2002 and 2006, Grubbs 1969).

There are well established procedures in statistics to identify true outliers, including visual inspection of graphs using particular techniques, such as probability and box-and-whisker plot, as well as statistical tests, such as Rosner's test and Dixon's test (USEPA 2002 and 2006). The treatment of confirmed outliers, however, requires a thorough evaluation of the causes of such measurements to ensure that purported outliers are not improperly excluded, thereby skewing the statistical analysis. Grubbs' *Procedures for Detecting Outlying Observations in Samples* (Grubbs 1969) states:

> "*An outlying observation, or 'outlier,' is one that appears to deviate markedly from other members of the sample in which it occurs. In this connection, the following two alternatives are of interest:*
>
> 1. *An outlying observation may be merely an extreme manifestation of the random variability inherent in the data. If this is true, the values should be retained and processed in the same manner as the other observations in the sample.*
> 2. *On the other hand, an outlying observation may be the result of gross deviation from prescribed experimental procedure or an error in calculating or recording the numerical value. In such cases, it may be desirable to institute an investigation to ascertain the reason for the aberrant value. The observation may even eventually be rejected as a result of the investigation, though not necessarily so. At any rate, in subsequent data analysis the outlier or outliers will be recognized as probably being from a different population than that of the sample values."*

USEPA itself has recognized the importance of properly evaluating apparent outliers and of not excluding data points simply based on their magnitude. USEPA's *Data Quality Assessment: Statistical Methods for Practitioners* divides (USEPA 2006) outliers into two groups: (1) "true outliers" resulting from transcription errors, data-coding errors, or measurement system problems such as instrument breakdown; and (2) "false outliers" representing true extreme values of a distribution (for instance, hot spots) and indicating more variability in the population than expected. This guidance states that "failure to remove true outliers or the removal of false outliers both lead to a distortion of estimates of population parameters."

In the data review, it is imperative that all sample data, including false outliers, are retained and are not arbitrarily removed. A proper statistical outlier evaluation will at least include the following steps, as discussed in USEPA's 2002 guidance:

- A careful investigation or review should be conducted for each statistical outlier, with scientific reasoning to ascertain the cause of the aberrant value (Grubbs 1969). If there is any error in collecting, transporting, or analyzing the sample, or transcribing the data, then the error should be corrected.
- If the error cannot be corrected, the associated true statistical outliers should be eliminated from the background dataset.[4]
- If no error can be identified or confirmed, false outliers should not be arbitrarily eliminated.

Thus, an outlier should not be eliminated from the background dataset, just because it is the greatest or lowest value in the dataset, or based on the perception that the outlying value is too high or too low to fit into the background dataset. In this case, the outliers "may be merely an extreme manifestation of the random variability inherent in the data [and] the values should be retained and processed in the same manner as the other observations in the sample" (Grubbs 1969). True outliers should be deleted from datasets, and false outliers should be retained. In cases where the nature of the outliers is either unknown or disputed, all statistical analyses should be conducted with both the full and truncated datasets to evaluate the effect of maintaining or eliminating the disputed outliers (USEPA 2002 and 2006). In cases involving actual or potential true outliers, their removal is required before a valid BTV can be calculated. In these cases, a statistically rigorous method must be used for outlier identification and removal.

As noted by USEPA, it is critical that the considerations outlined in this section are followed during the statistical analyses of the background data. Exercising caution not to improperly exclude "false" outliers, that accurately represent conditions at the background reference areas, will ensure technically defensible derivation of representative background concentrations, and will also avoid mistakes in the statistical approach when relying on a preconceived notion that outliers "distort statistics if used in any calculations" (USEPA 2002). Finally, once derived, these representative background concentrations should remain fixed for the duration of the remedial investigation and remedial response. Otherwise, the lack of certainty for stakeholders would be an impediment to the implementation of any remedy.

3.6 GEOCHEMICAL EVALUATION OF METALS CONCENTRATIONS

Geochemical evaluation is a tool with which to evaluate elemental (i.e., metals) concentrations in a given dataset, which may include exceedances of representative background concentrations. Consideration of geochemistry in the evaluation of trace metals concentrations in sediments does not require background reference area data for comparison, so, advantageously, it can be

[4] "Data points that are flagged as outliers should be eliminated from the dataset if field or laboratory records indicate that the sample location was not a reasonable reference area, or if there was a problem in collecting or analyzing the sample" (USEPA 2002).

used when it is not otherwise possible to identify background reference areas. However, geochemical evaluation is more convincing when data from the background reference areas are available for inclusion in the evaluation.

Geochemical evaluation can be used to determine if trace metal concentration values identified as outliers by statistical methods are actually the result of a release from the site, or if the outlier is simply a manifestation of the normal geochemical variability in the site dataset. When properly performed, geochemical evaluation provides mechanistic explanations for elevated concentrations (Thorbjornsen and Myers 2007). It is important to keep in mind that geochemical evaluation is not a simple graphical technique; all potential geochemical mechanisms, field observations, and available data need to be considered when examining element concentrations.

Background data can be evaluated by using the ratios of specific element pairs that are based on the known geochemical behavior of trace elements and their association with specific sediment minerals. The USEPA's Target Analyte List of 23 metals includes all of the common trace elements of interest, as well as the major elements that are used as reference elements.

Scatter plots may be prepared in which the concentration of a trace element of interest is plotted on the y-axis, and the concentration of a reference element, which represents the mineral (or organic compound) to which the trace element is adsorbed, is plotted on the x-axis. For further analysis, a ratio plot may also be prepared; like the scatter plot, the concentration of the trace element of interest is plotted on the y-axis, but the corresponding elemental ratio (the trace element concentration divided by the reference element concentration) is plotted on the x-axis. If a metal is found at an elevated concentration and that sample's elemental ratio lies outside the range of background elemental ratios, then that sample should be examined further. For example, the elevated ratio might reflect anthropogenic input of the trace element from the site, or it may indicate that the trace element concentration of that sample is controlled by another geochemical process, such as reducing conditions or trace metal precipitation in the sediment. If the sample lies within the range of background elemental ratios, then it is considered representative of background conditions.

The selection of a reference element for the scatter or ratio plot should be based on a careful comparison of the reference element and the trace element of interest, as well as consideration of site-specific geochemical processes. The following paragraphs provide a general overview of a few relevant elemental associations, but the reader is urged to consult the literature for additional information.[5]

- Clay minerals in the pH range of 6 to 8 have a strongly net negative surface charge, and attract positively charged trace metal ions, so that these trace metals adsorb to clay mineral surfaces. Aluminum is a primary component of all clay minerals, and detected aluminum concentrations in sediment serve as proxy indicators of the relative amounts of clay minerals (Thorbjornsen and Myers 2007). In addition, aluminum concentrations are generally not influenced by chemical releases and the element is not redox-active. For these reasons, the concentrations of positively

[5] Suggested literature is provided in Section 5.0.

charged trace metals (such as copper, lead, nickel, and zinc) commonly covary with aluminum concentrations in uncontaminated sediment samples.

- Iron oxides (including hydroxides, oxyhydroxides, hydrous oxides, and amorphous oxides) typically have a net positive surface charge in the pH range of 6 to 8. Detected iron concentrations serve as proxy indicators of the relative amounts of iron oxide minerals in sediment samples from oxic environments (Thorbjornsen and Myers 2007). Due to their net positive surface charge, they have an affinity for adsorption of negatively charged oxyanions (including arsenic, antimony, selenium, and vanadium), so that the concentrations of these trace metals commonly covary with iron concentration in uncontaminated samples from oxic sediments.
- Because metal species may be positively, neutrally, or negatively charged, other associations occur outside of these generalizations. Reference elements other than iron and aluminum (most typically manganese, which serves as a proxy indicator for manganese oxide minerals, in oxic sediments) are also used in geochemical evaluations. Grain size and TOC content are additional reference parameters that can be used to evaluate trace metal concentrations. For example, due to the affinity mercury has to adsorb on organic matter, covariance of mercury versus TOC concentrations may be observed in the absence of site-related mercury contamination.

Although quantitative statistical techniques are commonly applied to identify outliers or to develop pass-fail criteria for the presence of contamination, they are not recommended for geochemical evaluations that employ scatter plots or ratio plots, for many scientific reasons. For example, each trace element has varying degrees of correlation with the major element(s) with which it is associated; some trace elements have strong affinities for a particular mineral, while other elements will partition themselves among several minerals. Correlation coefficients, confidence limits, and prediction limits are highly influenced in a non-linear manner by outliers, as well as by the analytical uncertainty associated with estimated concentrations less than the reporting limit. Evaluation of a set of geochemical data can be quite complex, as the effects of redox, pH, and other processes should be considered. Trace-versus-major-element correlations are usually not linear and often possess some degree of curvature; this also translates to a higher range of elemental ratios and greater spread of the samples along the x-axis of a ratio plot.

Geochemical evaluation is an important line of evidence when evaluating background data and is commonly performed in conjunction with statistical evaluation of the dataset (refer to Section 3.4). A properly performed geochemical evaluation examines the interrelationships between elements, in the context of all available data, for the purpose of identifying the processes controlling the observed concentrations. Scatter plots and ratio plots, coupled with knowledge of the geochemical behavior of elements in the site-specific environment, may indicate that elevated concentrations, which would otherwise fail statistical outlier tests, have a natural and/or anthropogenic source that is not related to a site release. If the trace-versus-reference-element ratio lies within the ratio range of the representative background samples, then site-related contamination is not indicated.

4.0 Conclusions and Recommendations

Derivation of representative background concentrations is critical to the development of successful remedies for sediment sites. This document highlights concepts, data and considerations that are necessary for deriving representative background concentrations (including both anthropogenic and natural concentrations) to achieve a more complete understanding of historical and on-going sources to the site. In the absence of detailed guidance, these considerations may be overlooked or discounted when calculating representative background concentrations at sediment sites.

CSMs are critical tools for characterizing the complexity of sources to a site, migration pathways, receptors, and exposure pathways, and they inform the appropriate selection of background reference areas. The CSM developed for a site should include these key considerations (as outlined in this document):

- Anthropogenic inputs to the site, such as land use, urban runoff, direct discharge, sediment transport, atmospheric deposition, and source control.
- Natural characteristics of a site, such as sediment physical properties, hydrodynamic environment, sediment profile, and geochemistry.

Similarities between the site and the background reference areas are important, because they influence the transport and fate of contamination. Anthropogenic sources that cannot be controlled contribute on-going contamination and should be fully considered and incorporated into the CSM, as they represent anthropogenic background chemical concentrations that will persist on-site during and after any remedy. It may not be feasible to control all off-site sources of anthropogenic background prior to remediation, which should inform potential cleanup goals.

After selecting representative background reference areas and completing a targeted sampling program that uses sampling methods matching those used during site data collection, the data should be closely evaluated. The focus of the data evaluation should be on comparing site data with background data, using appropriate statistical approaches (along with geochemical evaluation for trace metals) to derive technically defensible representative background concentrations. During the data evaluation, it is imperative that false outliers are retained and are not arbitrarily removed, because natural variability occurs in a dataset. A statistically appropriate outlier evaluation should be performed on the background dataset, and the evaluation should include the key steps outlined in Section 3.5. Of critical importance, only true outliers should be removed from datasets, and false outliers should not be arbitrarily eliminated.

Representative background concentrations should remain fixed for the duration of the remedial investigation and remedial response. Otherwise, the lack of certainty for stakeholders would be an impediment to the implementation of any remedy. Collectively, the considerations and approaches outlined in this document should increase the ability to derive technically defensible representative background concentrations. These recommendations are offered to help inform, improve, and increase the consistency of sediment site remedy decision-making.

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